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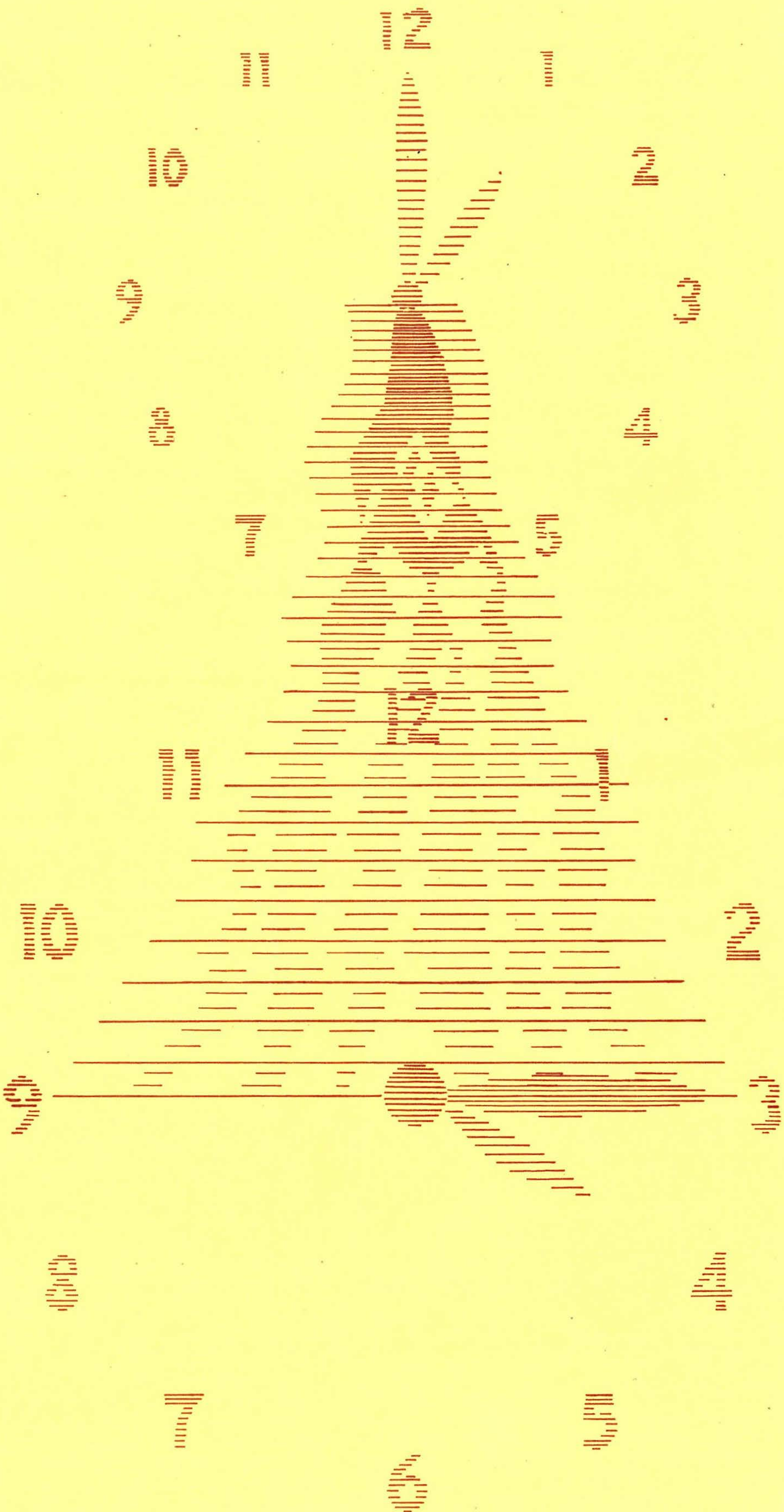
A technique for estimating the time of travel of water in Indiana streams



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Measured velocity rates compiled from the time-of-travel data collected in Indiana are related to 25, 50, 100, and 200 percent of the average discharge of streams shown in this report. Velocities at these discharges are significantly related to their respective watershed characteristics (average discharge and slope). Generalized relations of the velocities as functions of the streams' watershed characteristics are developed as multivariate regression equations using the data from each of the measured streams.

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A TECHNIQUE FOR ESTIMATING THE TIME OF TRAVEL OF WATER IN INDIANA STREAMS

By S. E. Eikenberry and L. G. Davis

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 76-9

Prepared in cooperation with
Indiana Department of Natural Resources
and Indiana State Board of Health

March 1976

UNITED STATES DEPARTMENT OF THE INTERIOR

Thomas S. Kleppe, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

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Indianapolis, Indiana 46202

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GLOSSARY

Average discharge.--The average volume of water, in cubic feet per second, that has been measured at a gaging station during the period of record of that station.

Channel slope.--The difference in elevation at points 10 and 85 percent of the distance along the channel from the downstream point in the reach to the upstream point in the reach divided by the distance between the two points, in feet per mile.

Contaminant.--Any substance that has an undesirable effect on water quality when discharged into a stream or water supply.

Cubic feet per second (ft^3/s).--The rate of discharge representing a volume of 1 cubic foot of water passing a given point during 1 second, equivalent to 7.48 gallons per second, 448.8 gallons per minute, or 0.028 cubic metres per second.

Discharge.--The volume of water that passes a given place within a given period of time.

Drainage area.--An area from which surface runoff is carried away by a single drainage system. Also called watershed and drainage basin.

Dye cloud.--The form that a single injection of a fluorescent dye takes after mixing and dispersion. Dye concentration of this cloud is uniform laterally, but is variable longitudinally.

Gaging station.--A particular site on a stream where systematic observations of gage height and discharge are obtained. The station usually has a recording gage for continuous measurement of the elevation of the water surface in the channel.

Leading edge.--The first or initial concentration of a dye cloud.

Natural flow.--Streamflow unrestricted by dams, reservoirs, diversions, or other manmade hydraulic structures.

Peak concentration.--The greatest concentration in a dye cloud.

Physiographic region.--Continuous area of similar climate, geologic structure, and materials creating similar geomorphic features.

Regression equation.--A mathematical relationship between a dependent variable and one or more independent variables.

Standard error of regression.--Refers to the standard error of estimate of the dependent variable. It is the standard deviation of the residual errors about a regression line used to predict the dependent variable converted to an average percentage. Approximately two-thirds of the data for the dependent variable are included within one standard error of estimate.

Steady flow.--The flow in a stream remains uniform with respect to time.

Time of travel.--Time of movement of waterborne particles from point to point in a stream for any flow condition.

Watershed.--See drainage area.

FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

The following factors may be used to convert the English units published herein to the International System of Units (SI):

English units	Multiply by	To obtain SI units
miles (mi)	1.609	kilometres (km)
feet per mile (ft/mi)	.189	metres per kilometre (m/km)
square miles (mi^2)	2.590	square kilometres (km^2)
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)
miles per hour (mi/h)	1.609	kilometres per hour (km/h)

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ABSTRACT

Estimates of the traveltime of waterborne particles in streams is important for pollution studies and in the event of spills of contaminants. This report provides data for the 16 Indiana streams on which time-of-travel information has been obtained and a means for estimating the velocity of any naturally flowing stream in Indiana with a drainage area of 80 square miles (210 square kilometres) or more.

Measured velocity rates compiled from the time-of-travel data collected in Indiana are related to 25, 50, 100, and 200 percent of the average discharge of streams shown in this report. Velocities at these discharges are significantly related to their respective watershed characteristics (average discharge and slope). Generalized relations of the velocities as functions of the streams' watershed characteristics are developed as multivariate regression equations using the data from each of the measured streams.

Examples of uses and applications of the measured data and the predictive equations are given.

INTRODUCTION

Purpose and Scope

When contaminants are spilled into streams, a quick, accurate prediction of their traveltime may be required to ensure the safety of downstream water users. For the 16 Indiana streams and rivers on which time of travel has been measured, accurate estimates of traveltimes can be obtained. However, should the spill occur on a stream on which no time-of-travel data has been obtained, other methods must be employed for estimating the traveltime of water in the stream.

The objective of this study was to develop a method for estimating the traveltime of water for both gaged and ungaged streams in Indiana. Equations were developed by relating stream velocity to slope and average discharge. These parameters and velocities, corresponding to 25, 50, 100, and 200 percent of the average discharge, from velocity-discharge curves for 46 accumulated stream reaches, were input data into a multi-variate correlation model. These input data are listed in tables 2 and 3 for each stream reach used in the study. Table 1 gives the locations of the gaging stations used.

The estimating equations given in this report apply only to naturally flowing streams with drainage areas of more than about 80 mi^2 (210 km^2). Estimated velocities in individual reaches of streams that have been measured for time of travel (fig. 1), can be interpolated from the data in the tables.

Acknowledgments

This report is the product of a cooperative agreement with the Indiana State Department of Natural Resources, the Indiana State Board of Health, and the U.S. Geological Survey. Their technical assistance is appreciated by the authors.

BASIC DATA

Time of travel of water and of waterborne solutes or particles can be measured by injection of a fluorescent-dye tracer into a stream. In theory, the dye simulates a soluble contaminant; that is, the particles of dye travel in the stream in the same manner as the water. Thus, the velocity of the water can be determined by measuring the time for movement of the dye from a point of injection to one or more downstream sampling points of determinable distance.

After injection into the water, the dye disperses laterally and longitudinally throughout the water and along the stream. Because the particles of dye travel at different rates, a cloud of various dye concentrations forms in the water. These concentrations, when plotted against time after injection, give the typical response curve shown in figure 2. Two points in this curve are sought--the arrival time of the initial concentration of the dye, or leading edge of the cloud (T_{LE}), and the arrival time of the maximum or peak concentration (T_{Pk}). The leading edge represents the movement of the fastest water particles in the stream. The peak represents the movement of the greatest number of water particles and approximates the average velocity. Actually, the average velocity is the centroid of the concentration versus time response curve (point A in fig. 2). This point, however, is very close to the time of peak concentration, T_{Pk}, which is more readily obtained.

Stream velocity varies directly with discharge. This variation is defined as a straight line on logarithmic coordinates for steady-flow conditions.

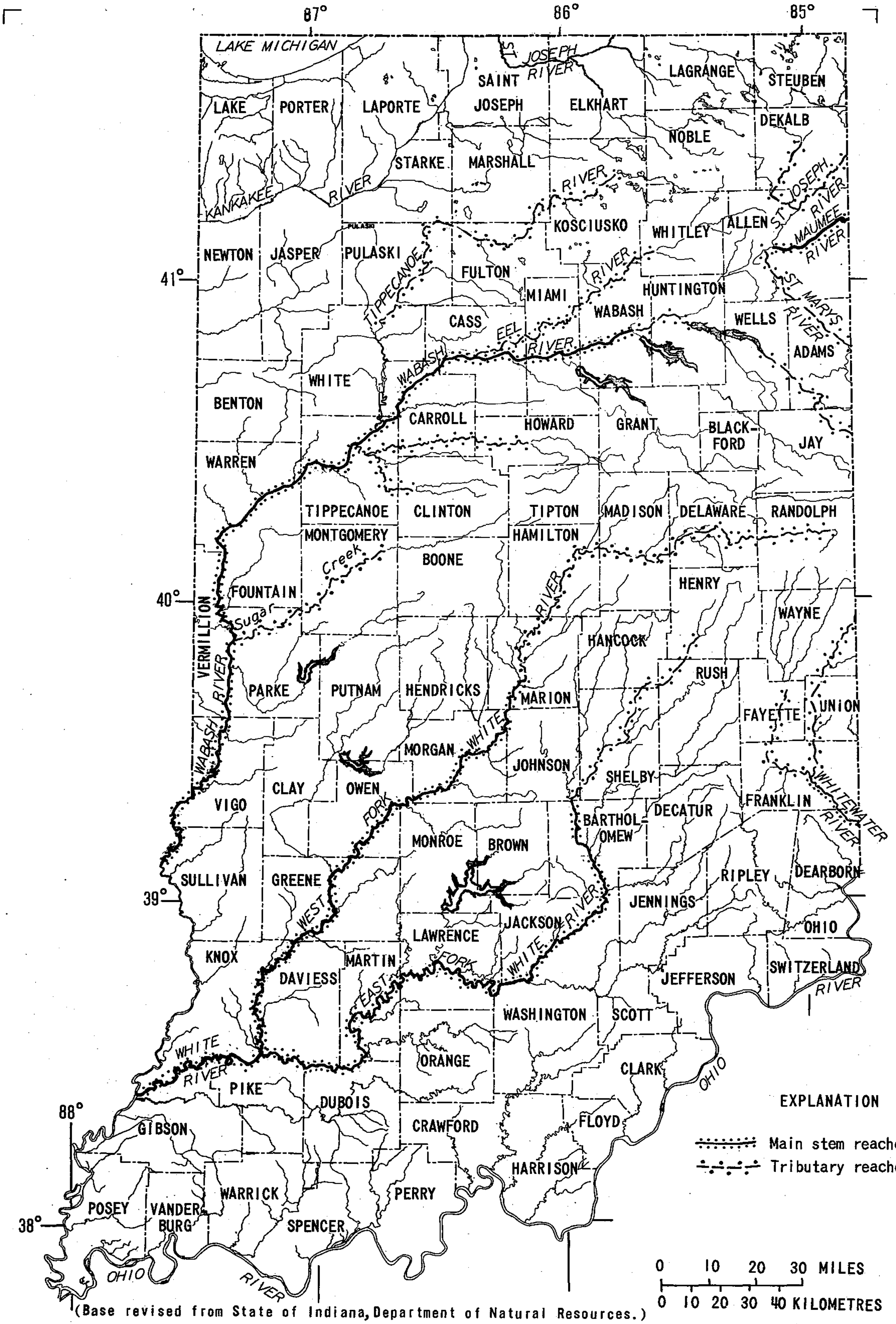


Figure 1.-- Stream reaches measured for time of travel of waterborne particles.

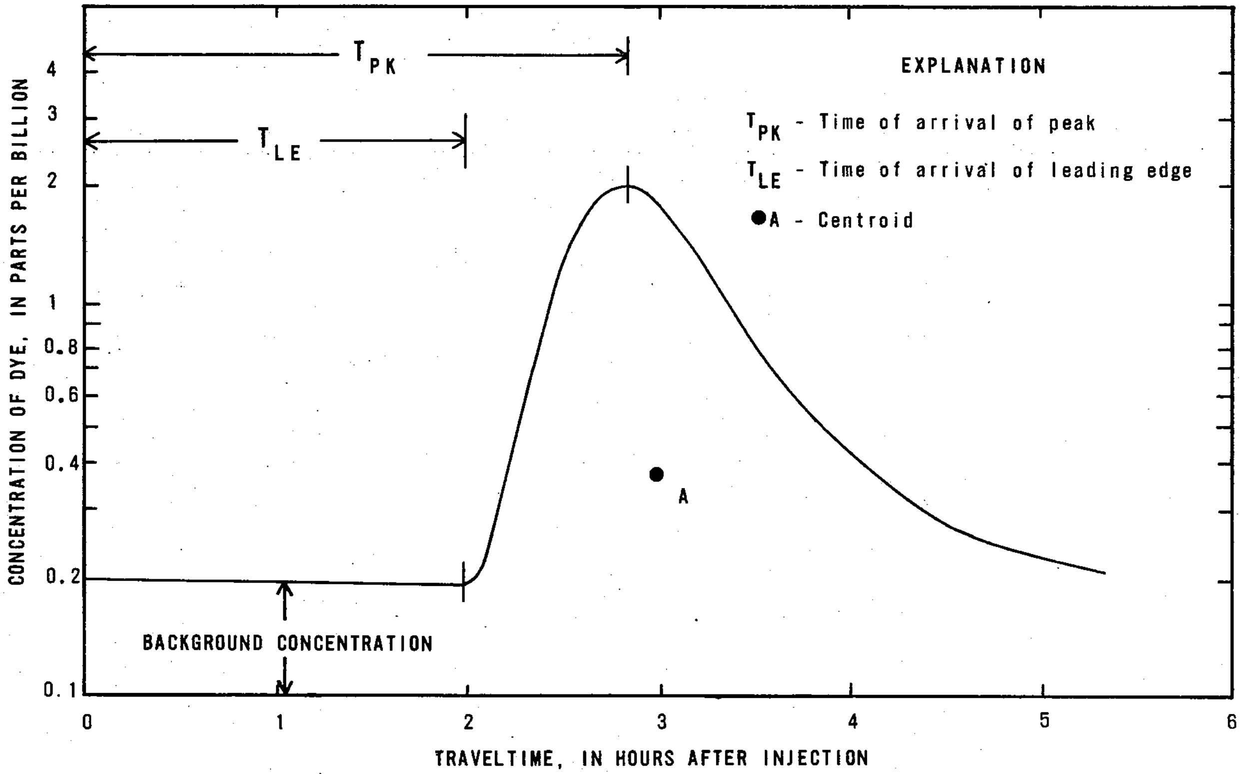


Figure 2.-- Concentration versus traveltime response curve resulting from an instantaneous dye injection.

Stream-Reach Data

The stream-reach equations in this study used time-of-travel data from 1,400 river mi (2,300 km) of the nearly 1,600 river mi (2,600 km) measured in the State. Approximately 340 subreaches were measured individually and then were accumulated into 46 main reaches for the 16 rivers and streams. Data were obtained on naturally flowing streams during periods of steady flow. Stream-reach data are given in tables 2 and 3.

Collection and Interpretation of Data

Time-of-travel data are collected by the instantaneous injection of a slug of dye into a stream at a bridge or other definite geographic location and timing the movement of the dye cloud as it passes one or more of the downstream locations. This is done for several short reaches or subreaches on each stream. The traveltime thus obtained is plotted against the concurrent discharge at the nearest gaging station.

Two traveltimes are needed to define a discharge-traveltime curve. For best definition, these traveltimes are obtained at as widely separated discharges as possible, within a range of 20 to 200 percent of the average discharge. (See example 1.) This is generally the range in which the discharge-traveltime curve is virtually linear. For a discharge at some point above 200 percent of the average, the velocity was found to have a lesser increase with increasing discharge; at some point below 20 percent of the average, the velocity was found to have a greater decrease with decreasing discharge.

In this study, discharge-traveltime data for each subreach of a stream were accumulated in downstream order to relate the traveltime for an entire reach where discharge is defined by a gaging station. The number of accumulated reaches for a stream corresponds to the number of gaging stations along the total reach that was measured. The discharge-traveltime curves apply only to conditions of steady flow.

Example 1. Traveltime versus discharge and velocity versus discharge curves

Time-of-travel measurements were made on the St. Marys River from Pleasant Mills to the Scheiman bridge, a distance of 14.4 mi (23.2 km). The discharges and traveltimes were:

Discharge (ft^3/s)	Average discharge (percent)	Traveltime: Leading edge (hours)	Traveltime: Peak (hours)
22	4.6	105	130
120	25	33.0	40.0
620	130	13.8	16.8
810	170	12.0	14.8
1,220	255	10.8	12.0

The long-term average discharge used for the reach is 478 ft^3/s (13.4 m^3/s) based on the U.S. Geological Survey gage on the St. Marys River at Decatur (station 04181500). These data are plotted in figure 3. Note that 120 ft^3/s (3.36 m^3/s), 620 ft^3/s (17.4 m^3/s), and 810 ft^3/s (22.7 m^3/s) all fall within the 20-200 percent of average discharge range, but 22 ft^3/s (0.62 m^3/s) and 1,220 ft^3/s (34.2 m^3/s) are outside this range.

The velocity versus discharge curve may be drawn from figure 3. The leading edge and the peak concentration traveltimes and velocities for 25, 50, 100, and 200 percent of the average discharge are obtained from the curves as follows:

		Traveltime		Velocity	
Average discharge (percent)	Discharge (ft^3/s)	Leading edge (hours)	Peak concentration (hours)	Leading edge (mph)	Peak concentration (mph)
25	120	33.0	40.0	0.44	0.36
50	239	23.0	28.5	.63	.51
100	478	15.6	19.4	.92	.74
200	956	10.9	13.5	1.32	1.07

The velocity-discharge curve for the reach is shown in figure 4.

MULTIPLE REGRESSION METHOD

Equations for estimating velocities of waterborne particles were developed by multiple regression techniques. The velocities at 25, 50, 100, and 200 percent of the average discharge were computed from the discharge-traveltime curves for each reach and were regressed against various watershed characteristics that influence stream velocity. The multiple regression equation has the form:

$$V_{Pk} = b\ A^x B^y$$

where:

V_{Pk} is the velocity of the peak of the dye cloud

A,B are watershed characteristics

x,y are regression coefficients

b is the regression constant

The equation relates observed stream velocities to physical watershed parameters. The independent variables (A and B) are parameters that significantly influence stream velocity and are easily obtained. These variables can be determined from available maps or streamflow reports.

Watershed Characteristics

The watershed characteristics used in the regression equations in this report may be determined from standard 7.5-minute Geological Survey topographic maps, annual water-resources-data reports for Indiana, river

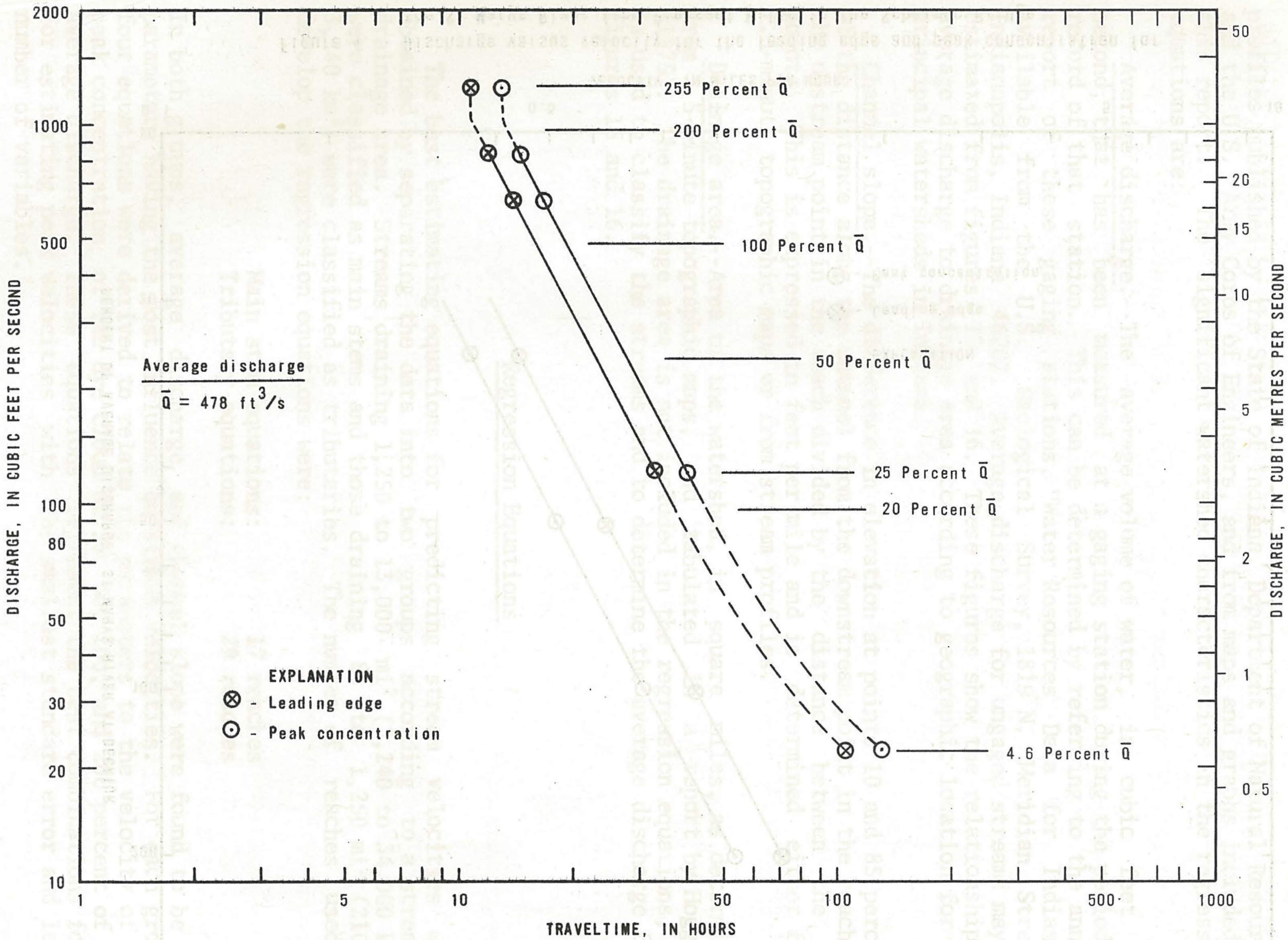


Figure 3.-- Discharge versus traveltime for the leading edge and peak concentration for the St Marys River from Pleasant Mills to the Scheiman Bridge.

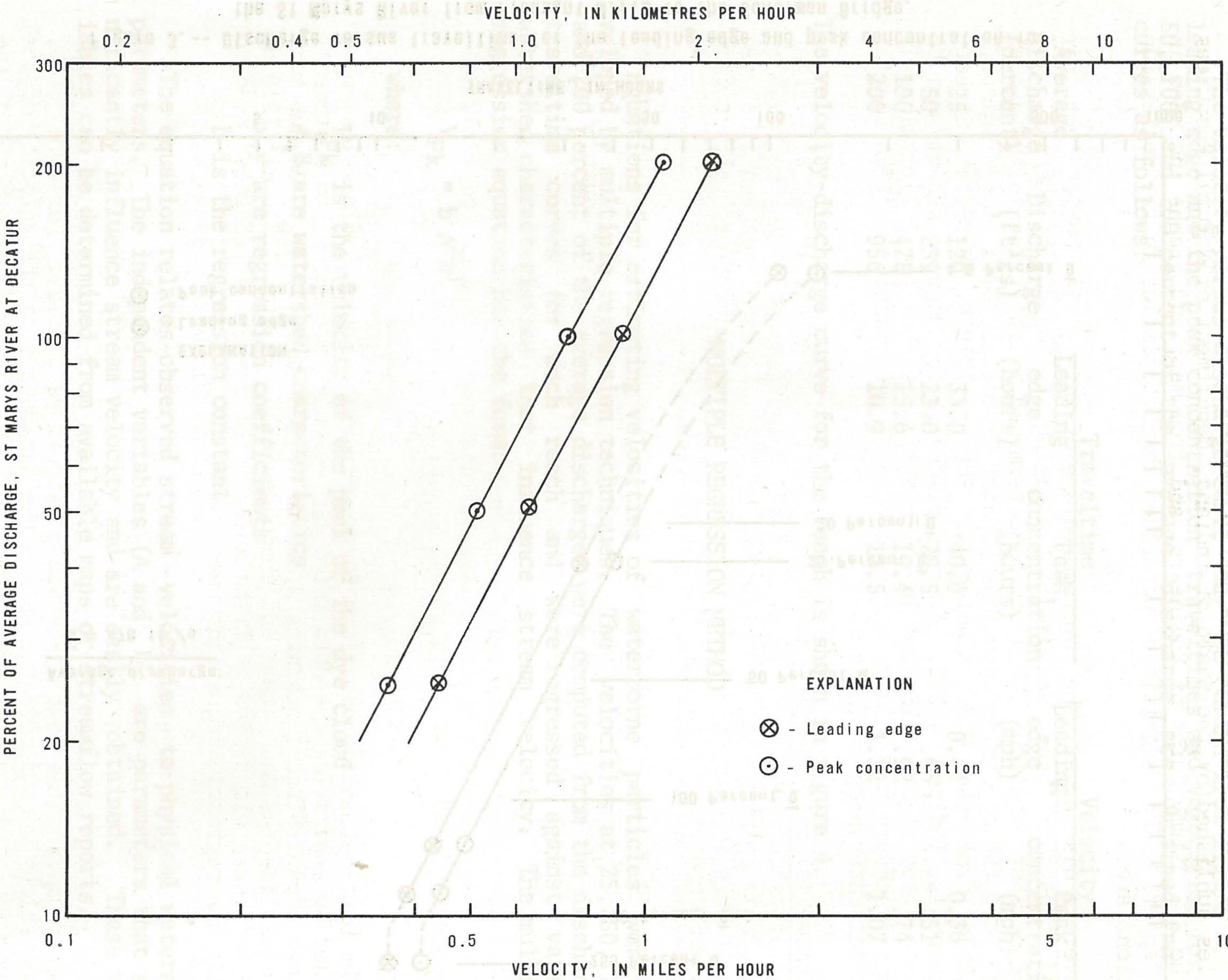


Figure 4.-- Discharge versus velocity for the leading edge and peak concentration for the St Marys River from Pleasant Mills to the Scheiman Bridge.

profiles published by the State of Indiana, Department of Natural Resources and the U.S. Army Corps of Engineers, and from maps and graphs included in this report. The significant watershed characteristics in the regression equations are:

Average discharge.--The average volume of water, in cubic feet per second, that has been measured at a gaging station during the period of record of that station. This can be determined by referring to the annual report of these gaging stations, "Water Resources Data for Indiana," available from the U.S. Geological Survey, 1819 N. Meridian Street, Indianapolis, Indiana 46202. Average discharge for ungaged streams may be estimated from figures 15 and 16. These figures show the relationship of average discharge to drainage area according to geographic location for the principal watersheds in Indiana.

Channel slope.--The difference in elevation at points 10 and 85 percent of the distance along the channel from the downstream point in the reach to the upstream point in the reach divided by the distance between the two points. This is expressed in feet per mile and is determined either from 7.5-minute topographic maps or from stream profiles.

Drainage area.--Area of the watershed, in square miles, as determined from 7.5-minute topographic maps, and tabulated in a report by Hoggatt (1975). The drainage area is not included in the regression equations, but is used to classify the streams and to determine the average discharge from figures 15 and 16.

Regression Equations

The best estimating equations for predicting stream velocities were obtained by separating the data into two groups according to a stream's drainage area. Streams draining 1,250 to 13,000 mi^2 (3,240 to 34,000 km^2) were classified as main stems and those draining 80 to 1,250 mi^2 (210 to 3,240 km^2) were classified as tributaries. The number of reaches used to develop the regression equations were:

Main stem equations:	17 reaches
Tributary equations:	29 reaches

In both groups, average discharge and channel slope were found to be the parameters having the most influence on stream velocities. For each group, four equations were derived to relate the parameters to the velocity of the peak concentration of the dye cloud at 25, 50, 100, and 200 percent of the average discharge. These equations represent the best combinations found for estimating peak velocities with the smallest standard error and least number of variables.

In general, the velocities in main-stem reaches are influenced most by variations in discharge. Velocities in tributary reaches vary more according to differences in both discharge and channel slope.

The regression equations for estimating peak velocities are defined by:

$$V_{Pk\ percent} = b\ Q^{x}S^{y}$$

where:

$V_{Pk\ percent}$ is the velocity of the peak concentration at percentage of average discharge, in miles per hour

b is the regression constant

Q is the average discharge, in cubic feet per second

S is the channel slope of the reach, in feet per mile

x,y are regression coefficients

Regression coefficients for main-stem reaches are:

Average discharge (percent)	Coefficient b	x	y	Standard error of regression (percent)
25	0.172	0.185	0.018	15
50	.259	.174	.072	11
100	.395	.159	.075	11
200	.604	.144	.107	12

Regression coefficients for tributary reaches are:

Average discharge (percent)	Coefficient b	x	y	Standard error of regression (percent)
25	0.053	0.300	0.229	18
50	.091	.269	.259	16
100	.177	.224	.248	18
200	.270	.224	.248	18

Graphical Solutions of Regression Equations

Estimates of peak velocities also may be obtained from the following graphical solutions of the regression equations. Figures 5 through 8 are for the main-stem reaches and figures 9 through 12 are for the tributary reaches.

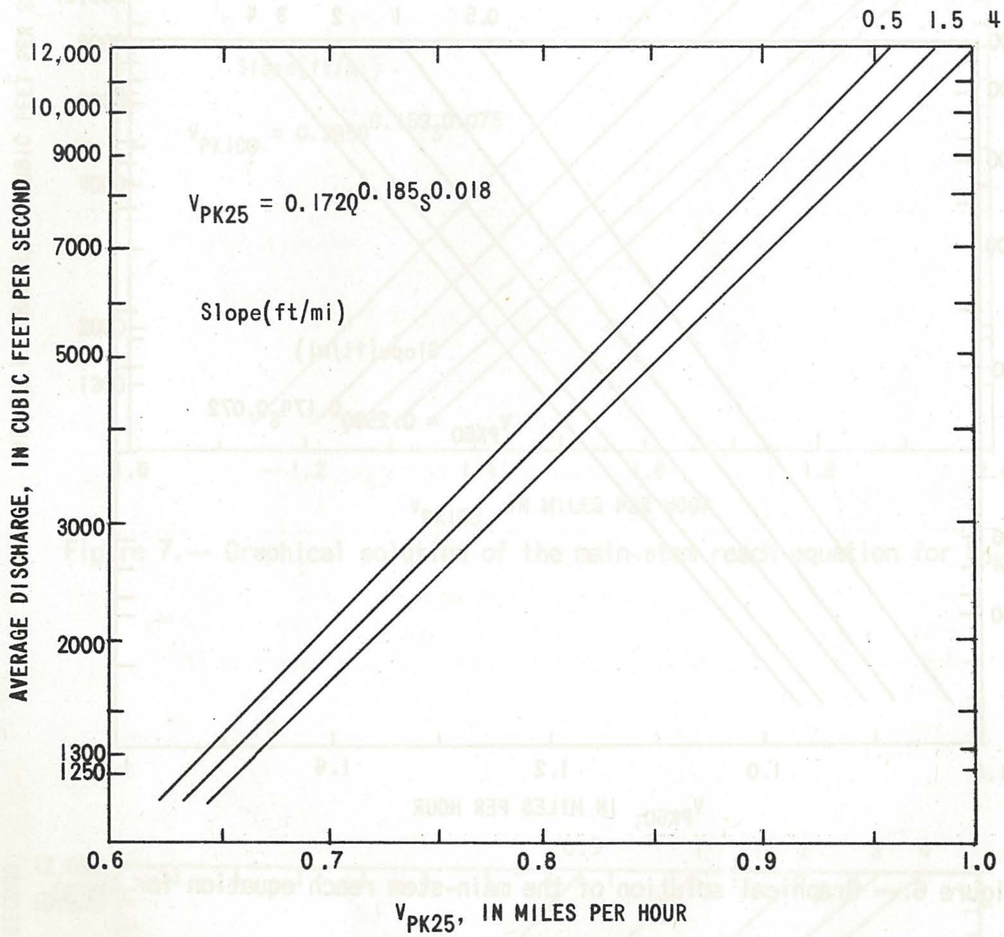


Figure 5.-- Graphical solution of the main-stem reach equation for V_{PK25}.

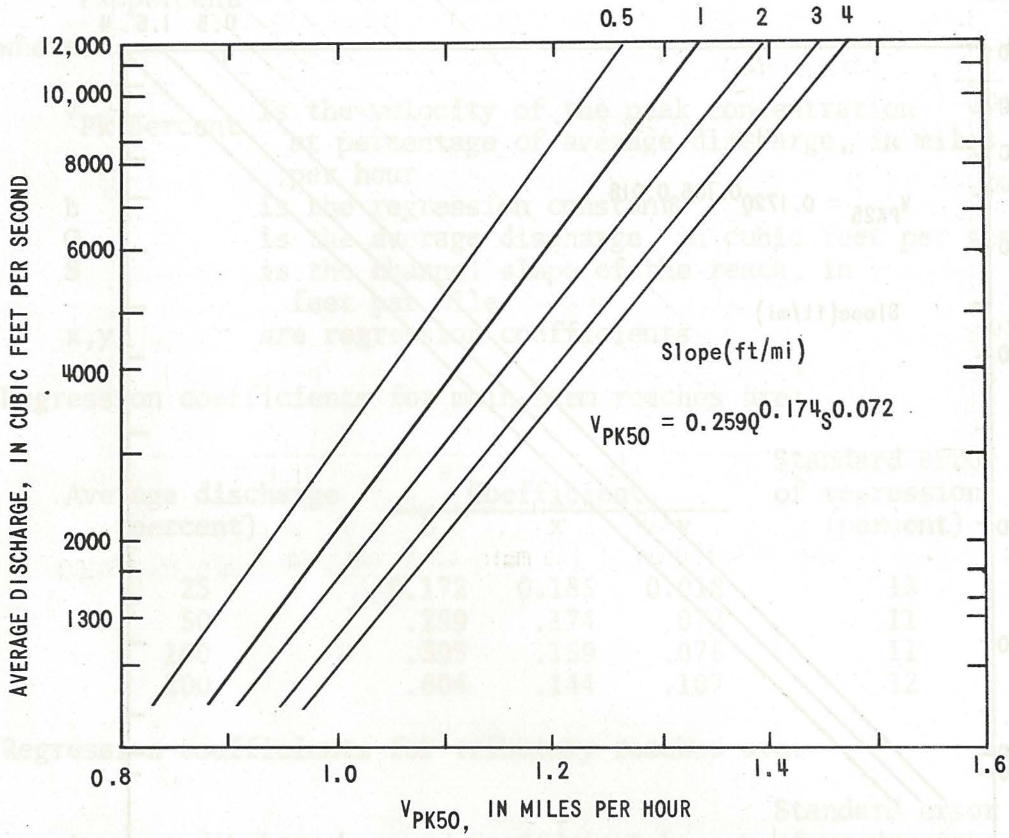


Figure 6.-- Graphical solution of the main-stem reach equation for V_{PK50}.

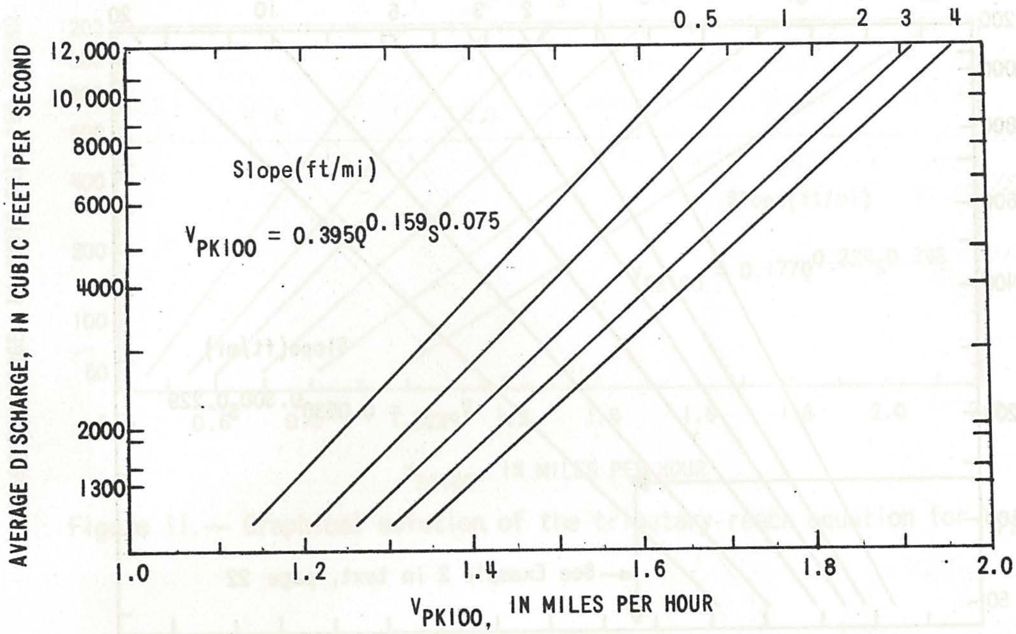


Figure 7.-- Graphical solution of the main-stem reach equation for V_{PK100}.

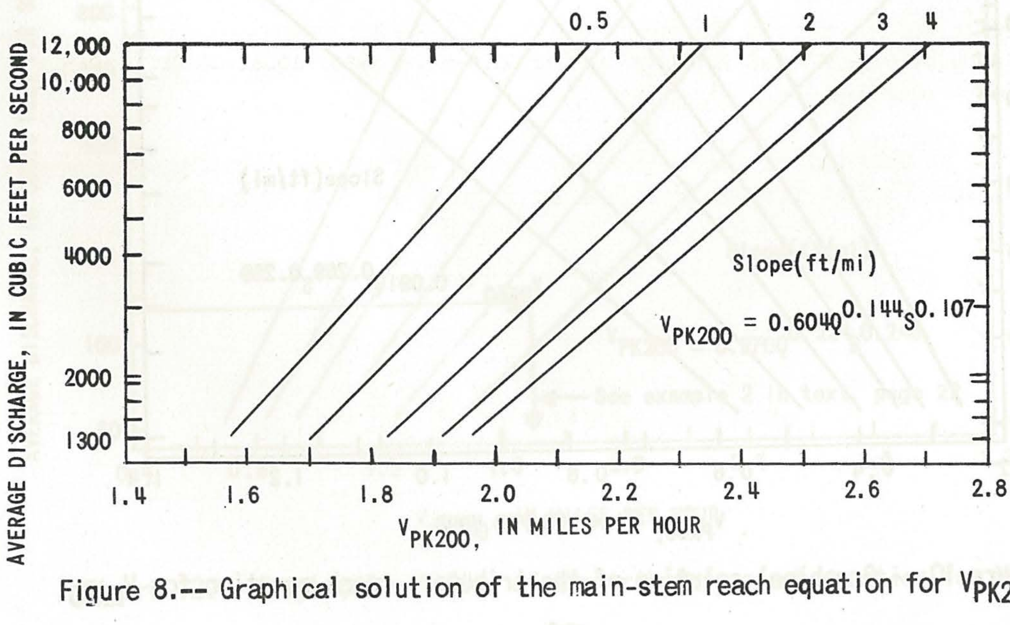


Figure 8.-- Graphical solution of the main-stem reach equation for V_{PK200}.

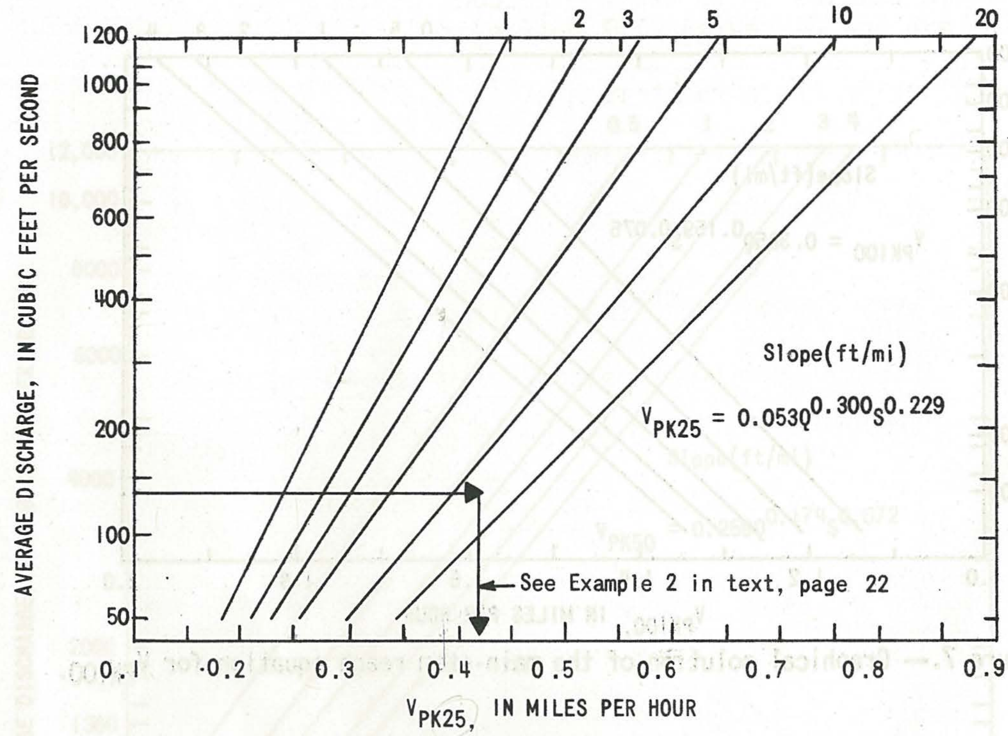


Figure 9.-- Graphical solution of the tributary reach equation for V_{PK25}.

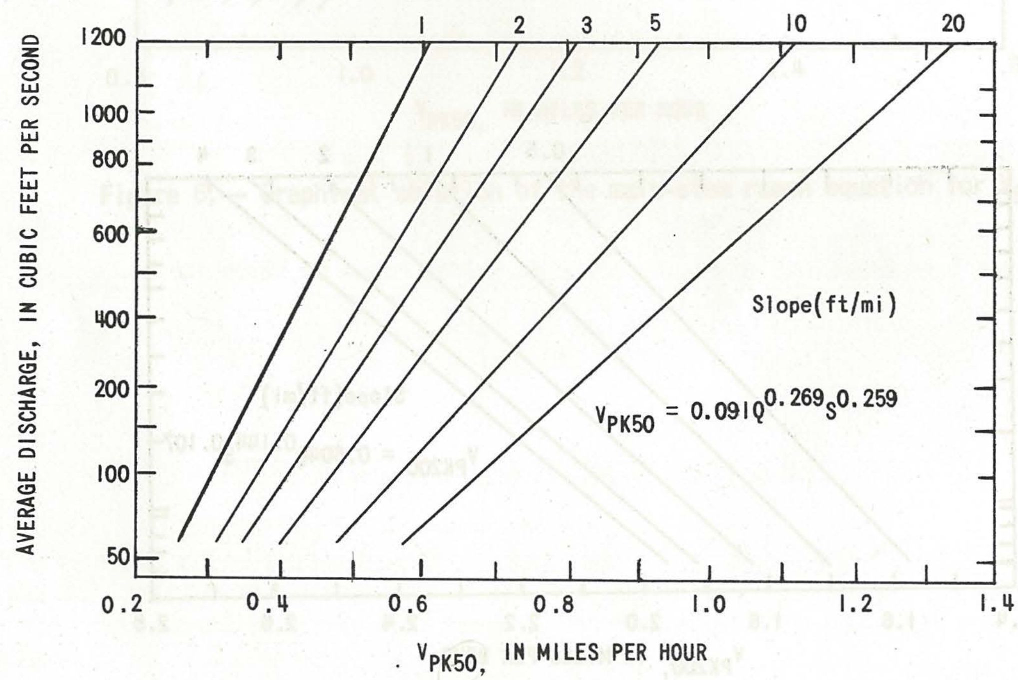


Figure 10.-- Graphical solution of the tributary-reach equation for V_{PK50}.

Jasper 262 360 cfs
Winslow 603
Channel Slope

446.2
3
449

405.5
44' Drop

91.5
41.3
50.2

Slope = 44/50 = .88'/mile

.25

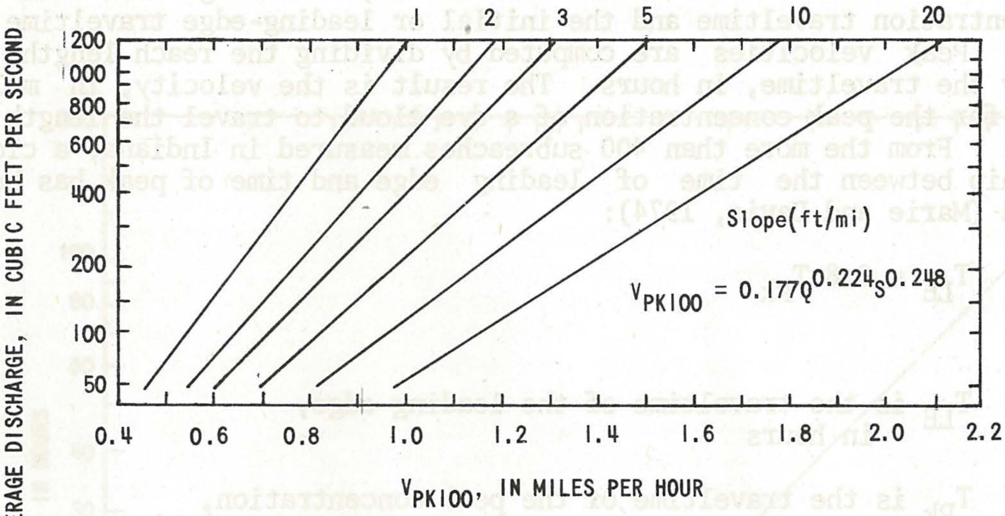


Figure 11.-- Graphical solution of the tributary-reach equation for V_{PK100}.

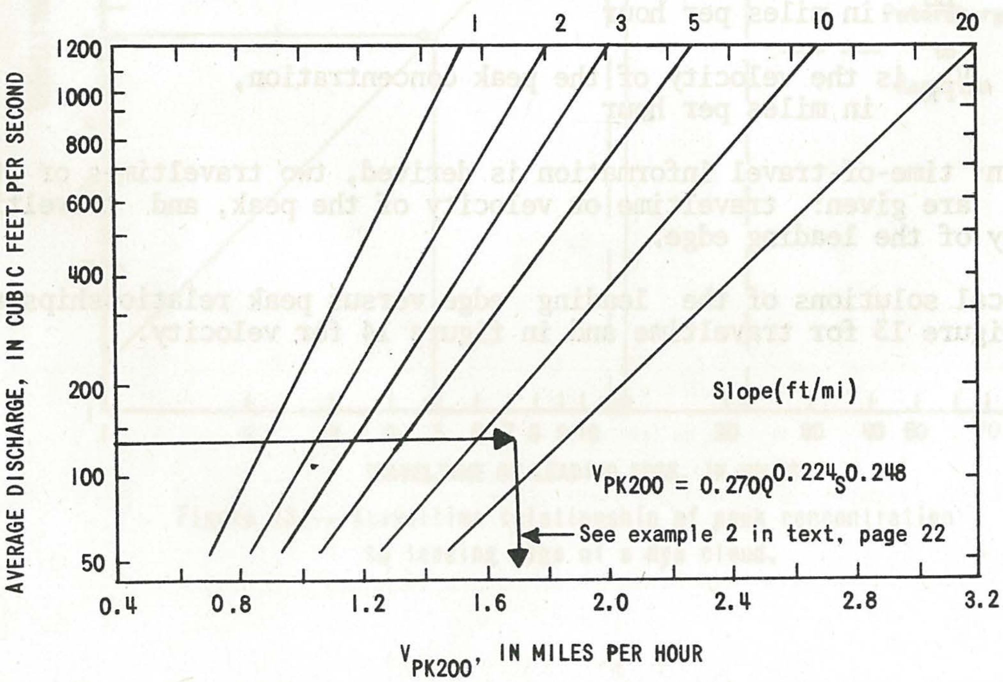


Figure 12.-- Graphical solution of the tributary-reach equation for V_{PK200}.

RELATIONSHIP OF PEAK AND LEADING-EDGE TRAVELTIMES AND VELOCITIES

When time-of-travel information is needed, knowledge of both the peak-concentration traveltime and the initial or leading-edge traveltime is required. Peak velocities are computed by dividing the reach length, in miles, by the traveltime, in hours. The result is the velocity, in miles per hour, for the peak concentration of a dye cloud to travel the length of the reach. From the more than 400 subreaches measured in Indiana, a close relationship between the time of leading edge and time of peak has been determined (Marie and Davis, 1974):

$$T_{LE} = 0.8\ T_{Pk}$$

where:

T_{LE} is the traveltime of the leading edge, in hours

T_{Pk} is the traveltime of the peak concentration, in hours

Therefore, velocity of the leading edge follows the relationship:

$$V_{LE} = 1.25\ V_{Pk}$$

where:

V_{LE} is the velocity of the leading edge, in miles per hour

V_{Pk} is the velocity of the peak concentration, in miles per hour

Thus, when time-of-travel information is derived, two traveltimes or two velocities are given: traveltime or velocity of the peak, and traveltime or velocity of the leading edge.

Graphical solutions of the leading edge versus peak relationships are given in figure 13 for traveltime and in figure 14 for velocity.

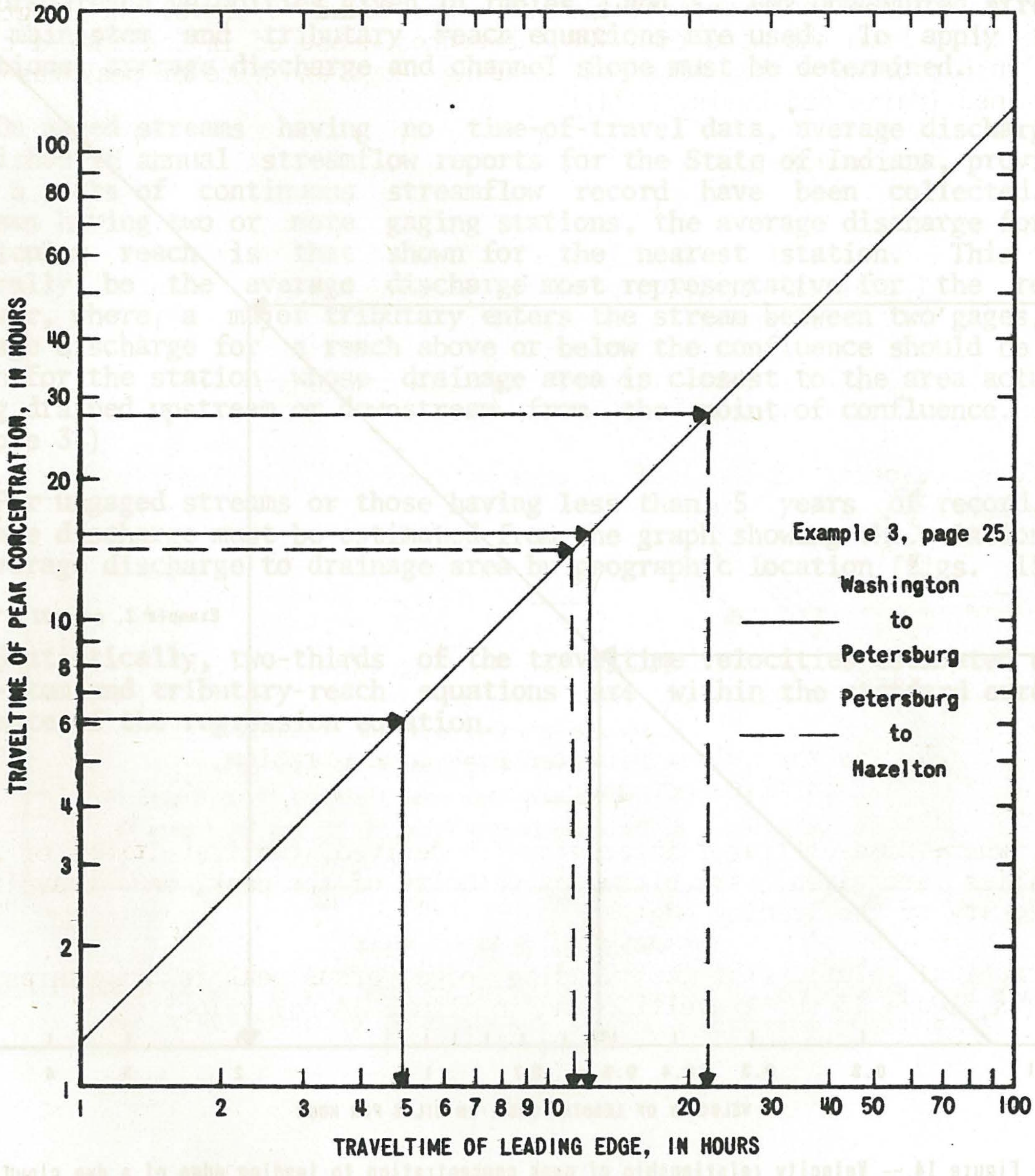


Figure 13.-- Traveltime relationship of peak concentration to leading edge of a dye cloud.

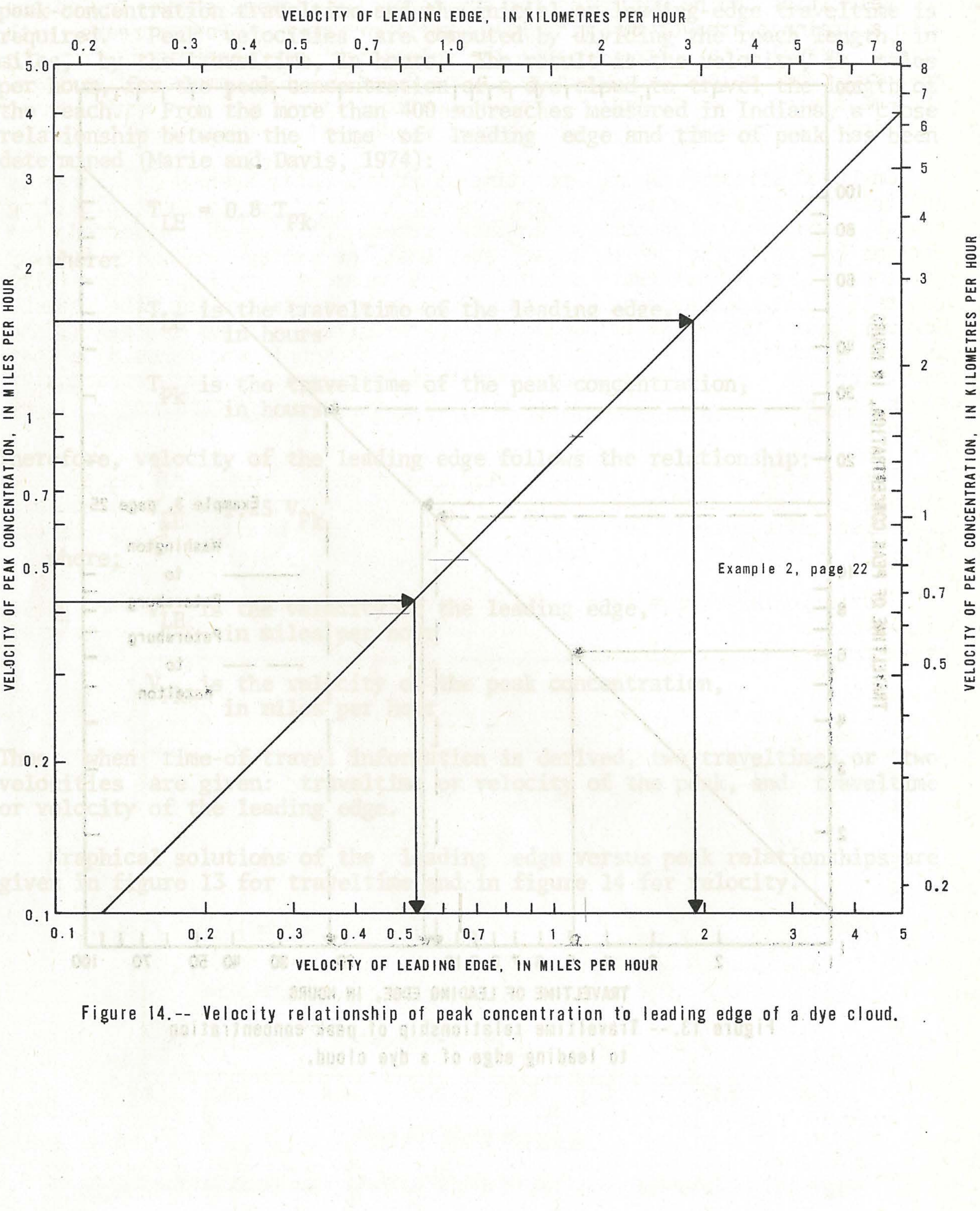


Figure 14.-- Velocity relationship of peak concentration to leading edge of a dye cloud.

APPLICATION

Velocities can be estimated for any naturally flowing stream in Indiana with a drainage area of 80 mi^2 (210 km^2) or more. For streams with time-of-travel data in the report, the velocities are estimated from the measured-reach velocities given in tables 2 and 3. For unmeasured streams, the main-stem and tributary reach equations are used. To apply these equations, average discharge and channel slope must be determined.

On gaged streams having no time-of-travel data, average discharge is published in annual streamflow reports for the State of Indiana, providing that 5 years of continuous streamflow record have been collected. On streams having two or more gaging stations, the average discharge for any particular reach is that shown for the nearest station. This will generally be the average discharge most representative for the reach. However, where a major tributary enters the stream between two gages, the average discharge for a reach above or below the confluence should be that shown for the station whose drainage area is closest to the area actually being drained upstream or downstream from the point of confluence. (See example 3.)

For ungaged streams or those having less than 5 years of record, the average discharge must be estimated from the graph showing the relationship of average discharge to drainage area by geographic location (figs. 15 and 16).

Statistically, two-thirds of the traveltime velocities estimated using main-stem and tributary-reach equations are within the standard error of estimate of the regression equation.

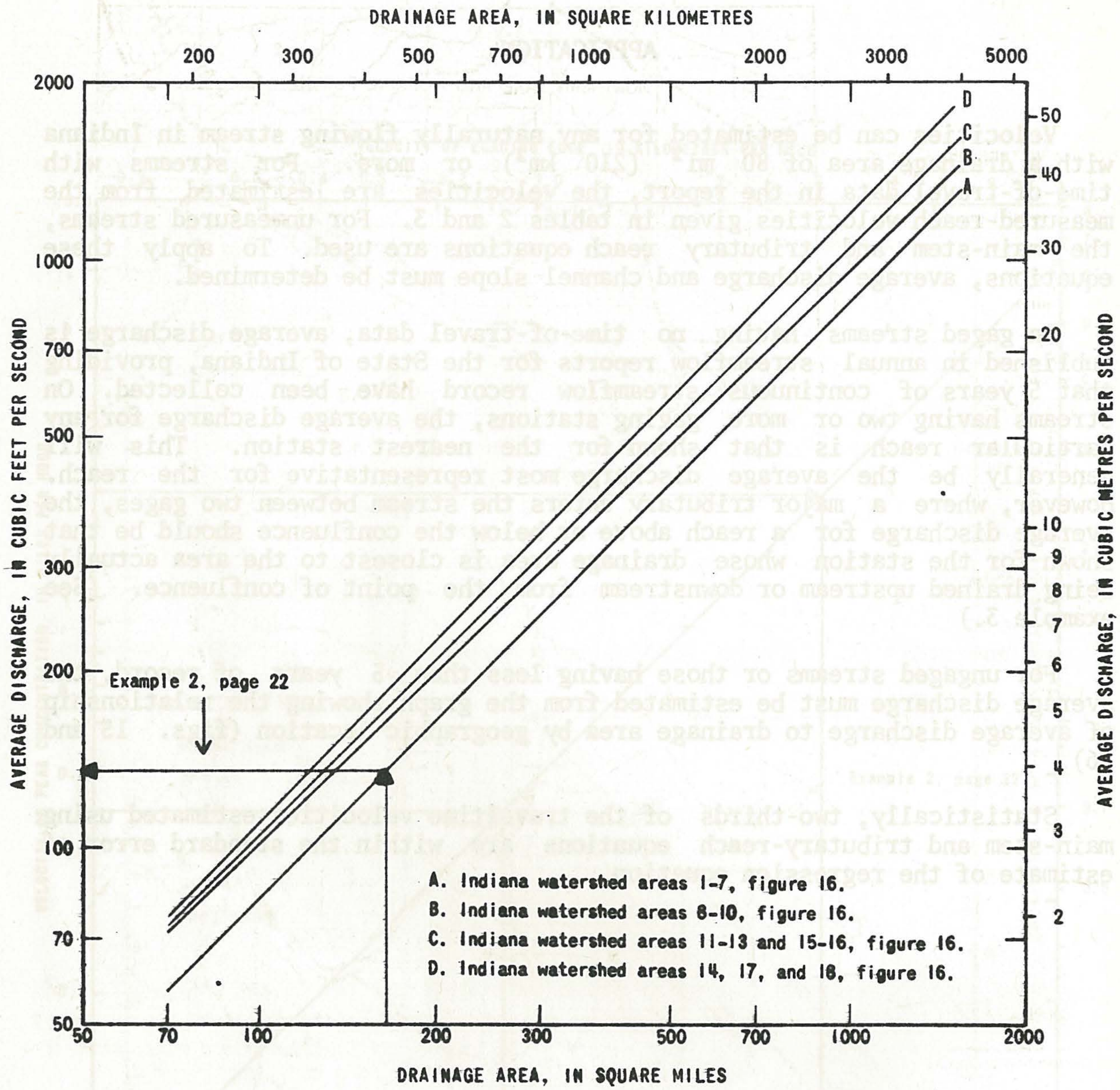
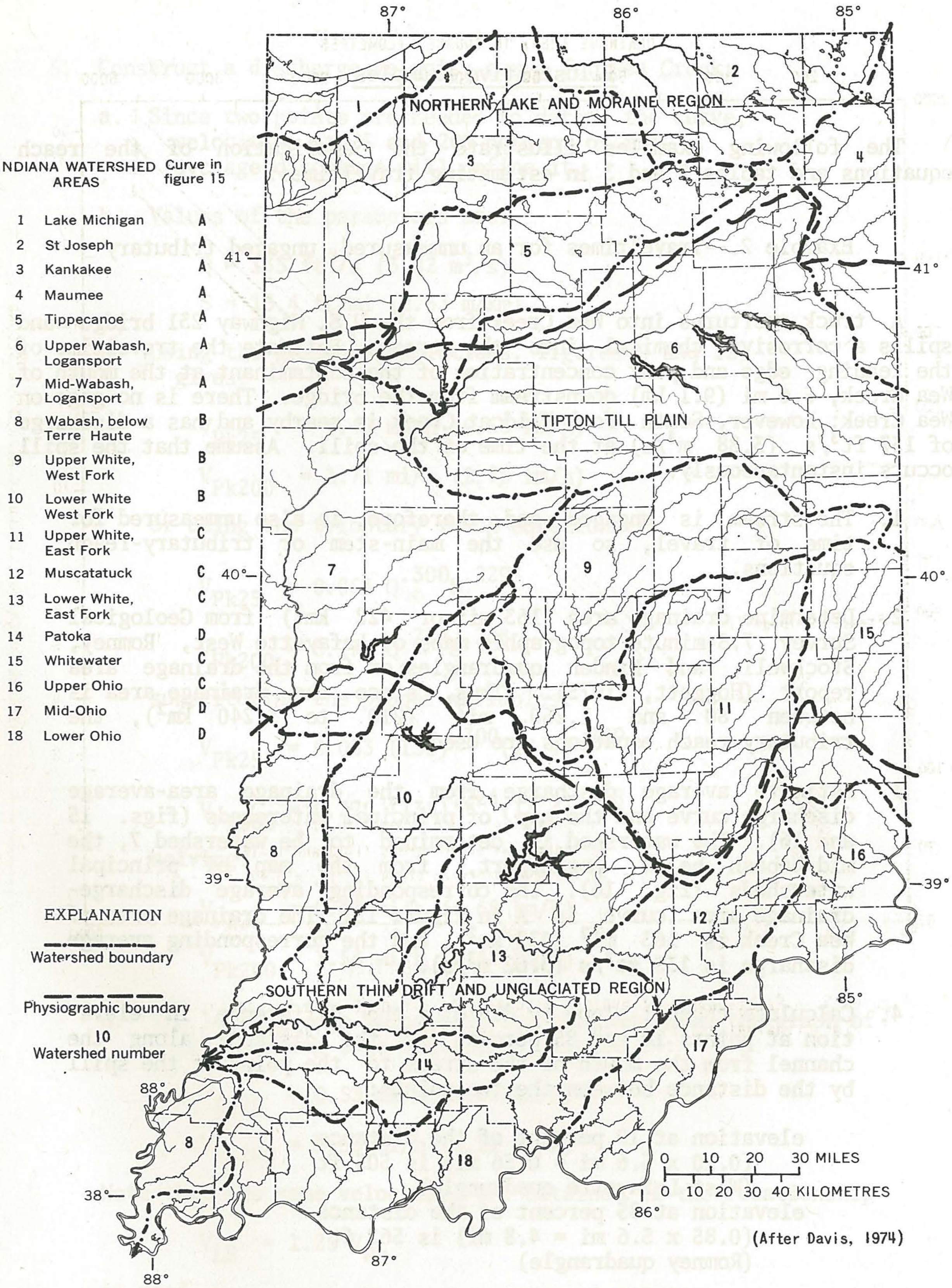


Figure 15.-- Relationship of average discharge to drainage area by geographic location for principal watersheds in Indiana. See figure 16 for location of streams.



(After Davis, 1974)

(Base revised from State of Indiana, Department of Natural Resources.)

Figure 16.-- Principal watersheds and major physiographic regions.

Illustrative Examples

The following examples illustrate the application of the reach equations and tables 2 and 3 in estimating traveltimes:

Example 2.--Traveltimes for an unmeasured, ungaged tributary

A truck overturns into Wea Creek from the U.S. Highway 231 bridge and spills a corrosive chemical into the stream. Estimate the traveltime of the leading edge and peak concentration of the contaminant at the mouth of Wea Creek, 5.6 mi (9.1 km) downstream from the bridge. There is no gage on Wea Creek; however, South Fork Wildcat Creek is nearby and has a discharge of 137 ft^3/s (3.88 m^3/s) at the time of the spill. Assume that the spill occurs instantaneously.

1. The stream is ungaged and, therefore, is also unmeasured for time of travel, so use the main-stem or tributary-reach equations.

2. Determine drainage area (163 mi^2 or 422 km^2) from Geological Survey 7.5-minute topographic maps of Lafayette West, Romney, Stockwell, and Linden quadrangles or from the drainage area report (Hoggatt, 1975). Thus, since the drainage area is between 80 and 1,250 mi^2 (210 to 3,240 km^2), the tributary-reach equations are used.

3. Estimate average discharge from the drainage area-average discharge curve and the map of principal watersheds (figs. 15 and 16). The watershed is determined to be watershed 7, the mid-Wabash below Logansport, from the map of principal watersheds (fig. 16). The corresponding average discharge-drainage area curve is A in figure 15. The drainage area of Wea Creek is 163 mi^2 (422 km^2), and the corresponding average discharge is 135 ft^3/s (3.82 m^3/s).

4. Calculate channel slope by dividing the difference in elevation at points 10 and 85 percent of the distance along the channel from the mouth of the stream to the point of the spill by the distance between the two points:

   elevation at 10 percent of the distance
   (0.10 x 5.6 mi = 0.56 mi) is 505 ft
   (West Lafayette quadrangle)
   elevation at 85 percent of the distance
   (0.85 x 5.6 mi = 4.8 mi) is 562 ft
   (Romney quadrangle)

$$\text{Slope} = \frac{562\text{-}505 \text{ ft}}{4.80\text{-}0.56 \text{ mi}} = 13.4 \text{ ft/mi}$$

5. Construct a discharge-velocity curve for Wea Creek:

   a. Since two points are needed to define the curve, velocities at 25 and 200 percent of the average discharge will define it.

   b. Values of the parameters are:

      $Q = 135\ ft^3/s\ (3.82\ m^3/s)$

      $S = 13.4\ ft/mi\ (2.53\ m/km)$

   c. Using the graphical solutions, figures 9 and 12, gives:

      $V_{Pk25} = 0.42\ mi/h\ (0.68\ km/h)$

      $V_{Pk200} = 1.71\ mi/h\ (2.75\ km/h)$

   or using the tributary reach equations:

      $V_{Pk25} = 0.053\ Q^{.300} S^{.229}$

      $V_{Pk200} = 0.270\ Q^{.224} S^{.248}$

   substituting the proper variables:

      $V_{Pk25} = 0.053\ (135)^{.300} (13.4)^{.229}$

      $V_{Pk200} = 0.270\ (135)^{.224} (13.4)^{.248}$

   solving:

      $V_{Pk25} = 0.42\ mi/h\ (0.68\ km/h)$

      $V_{Pk200} = 1.54\ mi/h\ (2.48\ km/h)$

   d. The leading edge velocities are obtained from the graph of peak-leading edge velocities, figure 14:

      $V_{LE25} = 0.53\ mi/h\ (0.85\ km/h)$

      $V_{LE200} = 1.93\ mi/h\ (3.11\ km/h)$

Note that the same velocities are obtained if the relationship

$$V_{LE} = 1.25\ V_{Pk}$$

is used.

e. The velocities are plotted versus the percentage average discharge in figure 17.

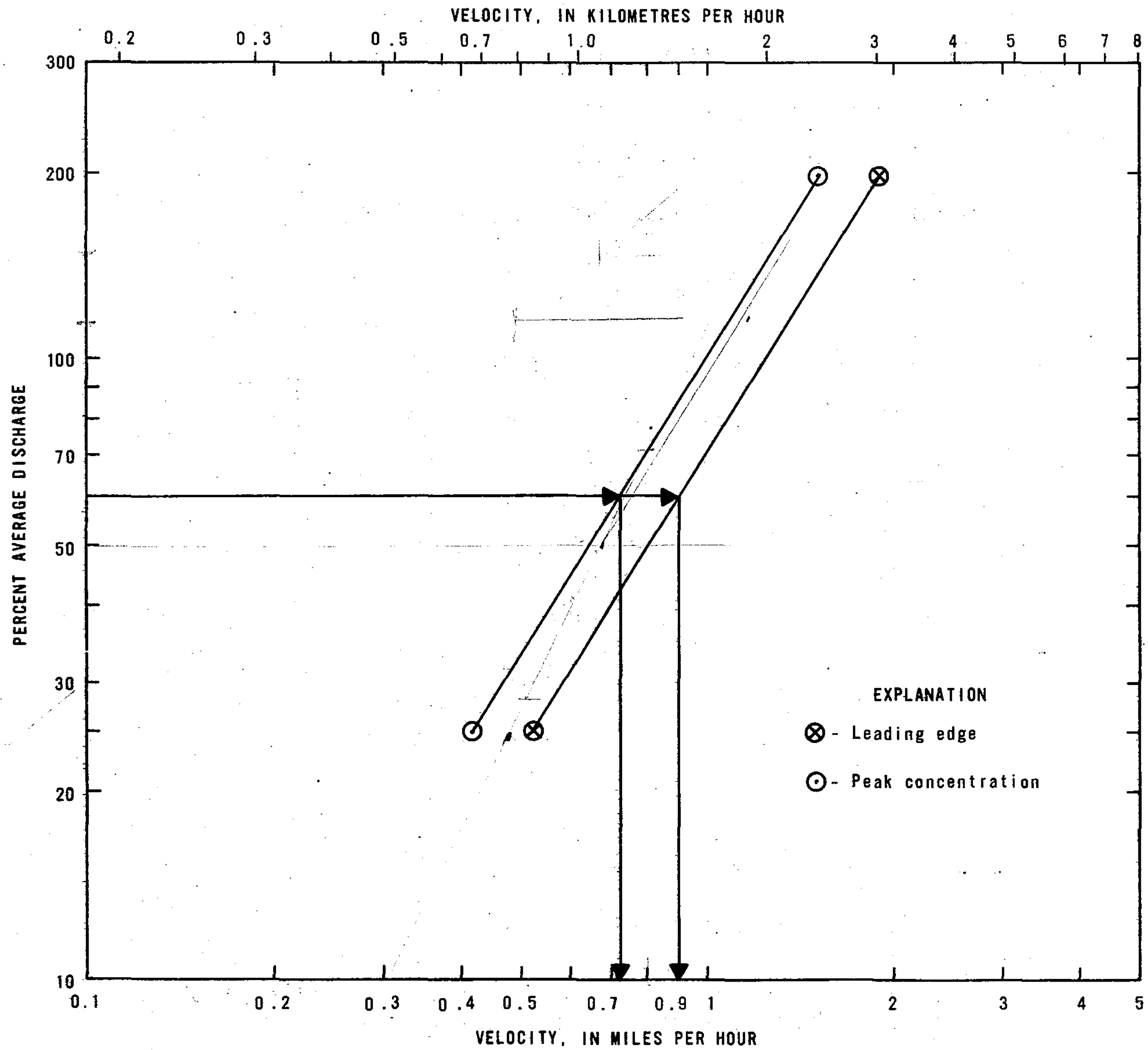


Figure 17.-- Velocity-discharge curves for Wea Creek.

6. Determine the percentage of the average discharge of Wea Creek at the time of the spill. Since Wea Creek is ungaged, assume that Wea Creek is at the same percentage of average discharge as the nearest gaged stream of similar size, in this case, South Fork Wildcat Creek. The discharge of South Fork Wildcat

Creek near Lafayette at the time of the spill is given as 137 ft^3/s (3.88 m^3/s). The average discharge is given in table 2 as 229 ft^3/s (6.48 m^3/s). Therefore, the average discharge, in percent, is:

$$\frac{137\ ft^3/s}{229\ ft^3/s} \times 100 = 60 \text{ percent}$$

7. Find the velocities of the leading edge and peak concentration on the velocity-discharge curves in figure 17.

$$V_{LE60} = 0.92 \text{ mi/h } (1.49 \text{ km/h})$$

$$V_{Pk60} = 0.72 \text{ mi/h } (1.16 \text{ km/h})$$

8. Calculate estimated traveltimes of the leading edge (T_{LE}) and peak (T_{Pk}) concentrations by dividing distance from U.S. Highway 231 bridge to the mouth of Wea Creek by the velocities:

$$T_{LE} = \frac{5.6 \text{ mi}}{0.92 \text{ mi/h}} = 6.1 \text{ hours}$$

$$T_{Pk} = \frac{5.6 \text{ mi}}{0.72 \text{ mi/h}} = 7.8 \text{ hours}$$

Thus, the estimated traveltime of the leading edge of the chemical to the mouth of Wea Creek is 6.1 hours and of the peak concentration is 7.8 hours after the spill.

Example 3.--Discharge-traveltime curves for a measured main stem

Determine the discharge-traveltime curves for the White River from the bridge on U.S. Highway 50 and 150 at Washington to the old U.S. Highway 41 bridge at Hazelton.

1. The map of time-of-travel measurements (fig. 1) shows that White River has been measured, and, therefore, the velocity information is in table 3.

2. The reaches that include the subreaches of interest are Worthington to Petersburg and Petersburg to Hazelton. Note that the drainage area of the White River above the East Fork White River is 5,372 mi^2 (13,913 km^2) (Hoggatt, 1975). Therefore, the Newberry gage (drainage area 4,688 mi^2 or 12,142 km^2) is closer to the actual area drained in the reach than the Petersburg gage (11,125 mi^2 or 28,814 km^2).

3. The gages on which the traveltimes are based are White River at Newberry (03360500), which has an average discharge of 4,485 ft^3/s (127.0 m^3/s), and White River at Petersburg (03374000), which has an average discharge of 11,190 ft^3/s (316.9 m^3/s).

4. The subreach distance from the bridge at U.S. Highway 50 and 150 at Washington, to State Highway 61 at Petersburg is 15.8 mi (25.4 km) and from Petersburg to old U.S. Highway 41 at Hazelton is 27.6 mi (44.4 km) from river profiles (State of Indiana, Department of Natural Resources, 1975) or from Geological Survey 7.5-minute topographic maps of Washington, Wheatland, Sandy Hook, Monroe City, Iona, Decker, and Patoka quadrangles.

5. Two points are needed to define each curve, so the peak-concentration velocity at 25 and 200 percent of each average discharge (from table 3) will be used.

Washington to Petersburg: Southport Rd to Martinsville

$$V_{Pk25} = 1.03 \text{ mi/h } (1.66 \text{ km/h})$$

$$V_{Pk200} = 2.55 \text{ mi/h } (4.11 \text{ km/h})$$

Petersburg to Hazelton: Martinsville to Spencer

$$V_{Pk25} = 1.00 \text{ mi/h } (1.61 \text{ km/h})$$

$$V_{Pk200} = 1.94 \text{ mi/h } (3.12 \text{ km/h})$$

6. Traveltimes of the peak (T_{Pk}) are determined by dividing the distances by the velocities:

Washington to Petersburg:

$$T_{Pk25} = \frac{15.8 \text{ mi}}{1.03 \text{ mi/h}} = 15.3 \text{ hours}$$

$$T_{Pk200} = \frac{15.8 \text{ mi}}{2.55 \text{ mi/h}} = 6.2 \text{ hours}$$

Petersburg to Hazelton:

$$T_{Pk25} = \frac{27.6 \text{ mi}}{1.00 \text{ mi/h}} = 27.6 \text{ hours}$$

$$T_{Pk200} = \frac{27.6 \text{ mi}}{1.94 \text{ mi/h}} = 14.2 \text{ hours}$$

7. Times of the leading edge (T_{LE}) are obtained from the graph showing the traveltime relationship of peak concentration to the leading edge (fig. 13), or from the relation:

$$T_{LE} = 0.8\ T_{Pk}$$

Washington to Petersburg:

$$T_{LE25} = 0.8 \text{ (15.3 hours)} = 12.2 \text{ hours}$$

$$T_{LE200} = 0.8 \text{ (6.2 hours)} = 5.0 \text{ hours}$$

Petersburg to Hazelton:

$$T_{LE25} = 0.8 \text{ (27.6 hours)} = 22.0 \text{ hours}$$

$$T_{LE200} = 0.8 \text{ (14.2 hours)} = 11.4 \text{ hours}$$

8. The traveltimes are plotted in figures 18 and 19 for their respective discharges:

Washington to Petersburg:

Average discharge (percent)	Discharge at Newberry (ft^3/s)	T_{LE} Leading edge (hours)	T_{Pk} Peak concentration (hours)
25	1,120	12.2	15.3
200	8,970	5.0	6.2

Petersburg to Hazelton:

Average discharge (percent)	Discharge at Petersburg (ft^3/s)	T_{LE} Leading edge (hours)	T_{Pk} Peak concentration (hours)
25	2,800	22.0	27.6
200	22,400	11.4	14.2

To determine the traveltime from Washington to Hazelton, the subreach traveltimes are summed. Note that the only information necessary to estimate the traveltimes are the discharges at Newberry and Petersburg.

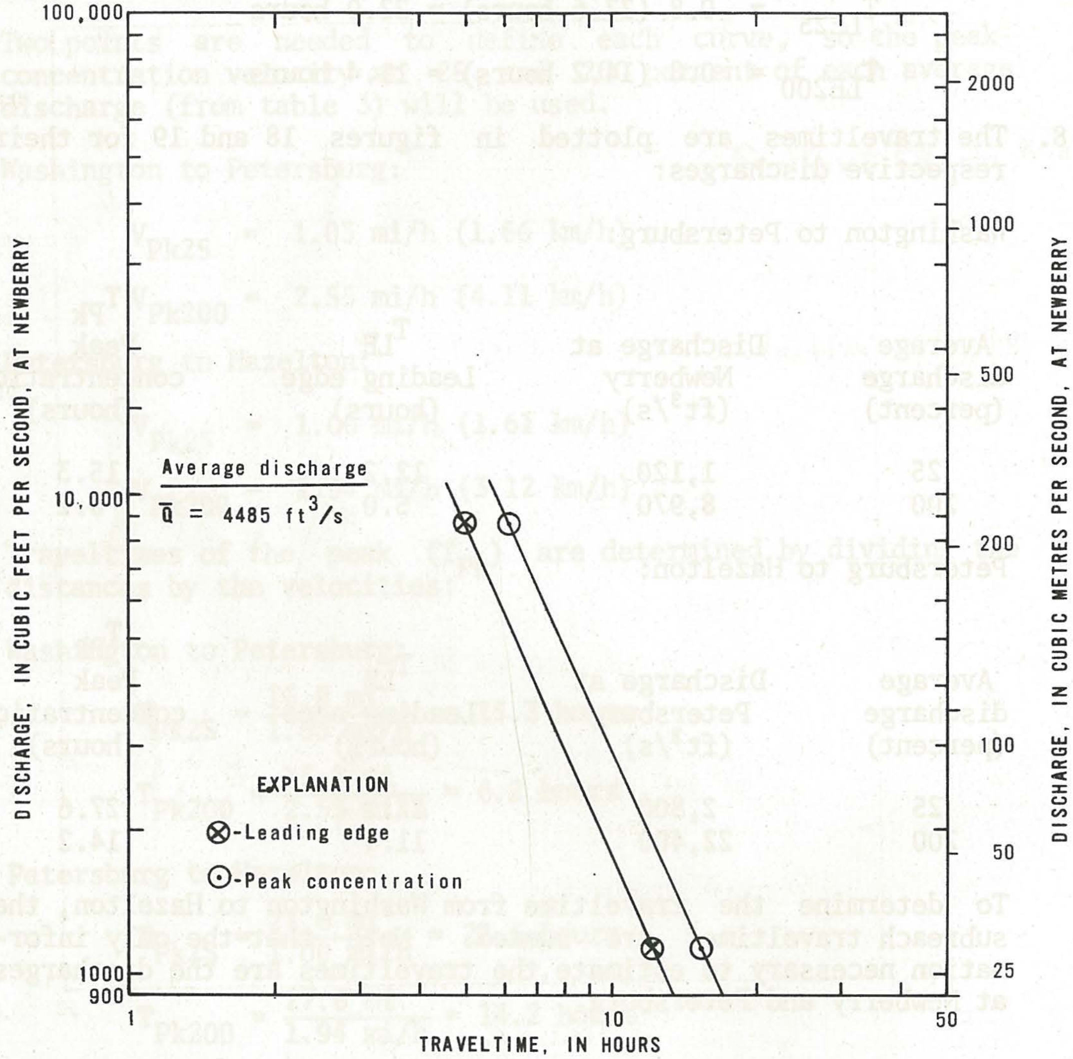


Figure 18.-- Discharge-traveltime curve for the White River from U.S. Highways 50 and 150 at Washington to State Highway 61 at Petersburg.

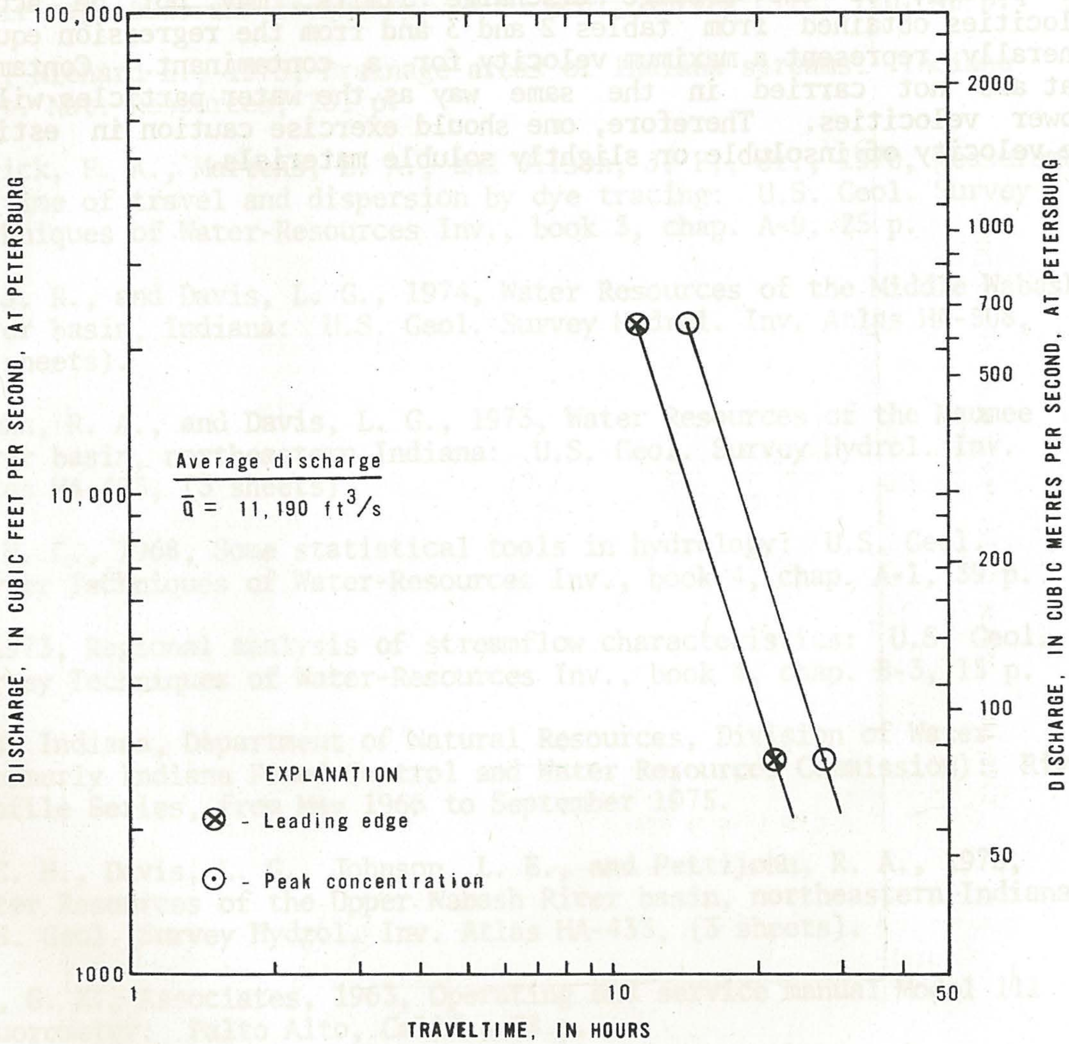


Figure 19.--Discharge-traveltime curve for the White River from State Highway 61 at Petersburg to old U.S. Highway 41 at Hazelton.

Limits of Application

The reach velocity equations in this report should be applied only to naturally flowing streams that have a drainage area of at least 80 mi^2 (210 km^2) and that are in a steady flow condition within the limits of 20 to 200 percent of average discharge. Traveltime estimates of streams that have dams in the reaches, have a fluctuating stage, or are outside of the 20 to 200 percent of the average discharge limits, may not be accurate. Velocities obtained from tables 2 and 3 and from the regression equations generally represent a maximum velocity for a contaminant. Contaminants that are not carried in the same way as the water particles will have slower velocities. Therefore, one should exercise caution in estimating the velocity of insoluble or slightly soluble materials.

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Table 1.--Location of U.S. Geological Survey gaging stations.

Number	Station Name
03275000	Whitewater River near Alpine, Ind., Lat 39°34'23", long 85°09'27", in SW 1/4 SE 1/4 sec.14, T.13 N., R.12 E., Fayette County.
03275500	East Fork Whitewater River at Richmond, Ind., Lat 39°48'24", long 84°54'26", in NW 1/4 SW 1/4 sec.8, T.13 N., R.1 W., Wayne County.
03275600	East Fork Whitewater River at Abington, Ind., Lat 39°43'57", long 84°57'35", NE 1/4 SW 1/4 sec.2, T.12 N., R.2 W., Union County.
03276500	Whitewater River at Brookville, Ind., Lat 39°24'24", long 85°00'46", in NE 1/4 NW 1/4 sec.32, T.9 N., R.2 W., Franklin County.
03322500	Wabash River near New Corydon, Ind., Lat 40°33'50", long 84°48'10", in NE 1/4 SE 1/4 sec.3, T.24 N., R.15 E., Jay County.
03322900	Wabash River at Linn Grove, Ind., Lat 40°39'22", long 85°01'58", in SE 1/4 SE 1/4 sec.34, T.26 N., R.13 E., Adams County.
03323500	Wabash River at Huntington, Ind., Lat 40°51'20", long 85°29'53", in SW 1/4 NE 1/4 sec.27, T.28 N., R.9 E., Huntington County.
03325000	Wabash River at Wabash, Ind., Lat 40°47'25", long 85°49'13", in SE 1/4 NW 1/4 sec.14, T.27 N., R.6 E., Wabash County.
03327500	Wabash River at Peru, Ind., Lat 40°44'35", long 86°05'45", in SE 1/4 NE 1/4 sec.32, T.27 N., R.4 E., Miami County.
03328000	Eel River at North Manchester, Ind., Lat 40°59'55", long 85°45'50", in NE 1/4 NE 1/4 sec.5, T.29 N., R.7 E., Wabash County.
03328500	Eel River near Logansport, Ind., Lat 40°46'55", long 86°15'50", in NE 1/4 SE 1/4 sec.14, T.27 N., R.2 E., Cass County.
03329000	Wabash River at Logansport, Ind., Lat 40°44'47", long 86°22'39", in SW 1/4 NE 1/4 sec.35, T.27 N., R.1 E., Cass County.
03329500	Wabash River at Delphi, Ind., Lat 40°35'26", long 86°41'54", in SE 1/4 SE 1/4 sec.24, T.25 N., R.3 W., Carroll County.

Table 1.--Location of U.S. Geological Survey gaging stations--Continued

Number	Station Name
03330500	Tippecanoe River at Oswego, Ind., Lat 41°19'14", long 85°47'21", in NE 1/4 NE 1/4 sec.14, T.33 N., R.6 E., Kosciusko County.
03331500	Tippecanoe River near Ora, Ind., Lat 41°09'26", long 86°33'49", in SE 1/4 SE 1/4 sec.6, T.31 N., R.1 W., Pulaski County.
03333700	Wildcat Creek at Kokomo, Ind., Lat 40°28'24", long 86°09'26", in NE 1/4 NW 1/4 sec.2, T.23 N., R.3 E., Howard County.
03334000	Wildcat Creek at Owasco, Ind., Lat 40°27'50", long 86°38'15", in SE 1/4 SE 1/4 sec.4, T.23 N., R.2 W., Carroll County.
03334500	South Fork Wildcat Creek near Lafayette, Ind., Lat 40°25'04", long 86°46'05", in SW 1/4 SW 1/4 sec.21, T.23 N., R.3 W., Tippecanoe County.
03335000	Wildcat Creek near Lafayette, Ind., Lat 40°26'26", long 86°49'46", in SE 1/4 NE 1/4 sec.14, T.23 N., R.4 W., Tippecanoe County.
03335500	Wabash River at Lafayette, Ind., Lat 40°25'19", long 86°53'49", in NE 1/4 SW 1/4 sec.20, T.23 N., R.4 W., Tippecanoe County.
03336000	Wabash River at Covington, Ind., Lat 40°08'24", long 87°24'20", in NE 1/4 NW 1/4 sec.35, T.20 N., R.9 W., on Fountain-Warren County line.
03339500	Sugar Creek at Crawfordsville, Ind., Lat 40°02'56", long 86°53'58", in SW 1/4 NW 1/4 sec.32, T.19 N., R.4 W., Montgomery County.
03340000	Sugar Creek near Byron, Ind., Lat 39°55'52", long 87°07'33", in NW 1/4 SW 1/4 sec.8, T.17 N., R.6 W., Parke County.
03340500	Wabash River at Montezuma, Ind., Lat 39°47'33", long 87°22'26", in SE 1/4 NE 1/4 sec.35, T.16 N., R.9 W., Parke County.
03341500	Wabash River at Terre Haute, Ind., Lat 39°28'00", long 87°25'08", in NE 1/4 SW 1/4 sec.21, T.12 N., R.9 W., Vigo County.
03347000	White River at Muncie, Ind., Lat 40°12'15", long 85°23'14", in SE 1/4 NW 1/4 Hackley Reserve, Delaware County.

Table 1.--Location of U.S. Geological Survey gaging stations--Continued

Number	Station Name
03348000	White River at Anderson, Ind., Lat 40°06'22", long 85°40'20", in SW 1/4 SW 1/4 sec.7, T.19 N., R.8 E., Madison County.
03349000	White River at Noblesville, Ind., Lat 40°02'50", long 86°01'00", in SE 1/4 SE 1/4 sec.36, T.19 N., R.4 E., Hamilton County.
03351000	White River near Nora, Ind., Lat 39°54'35", long 86°06'20", in NW 1/4 NW 1/4 sec.20, T.17 N., R.4 E., Marion County.
03353000	White River at Indianapolis, Ind., Lat 39°45'05", long 86°10'30", in NW 1/4 NW 1/4 sec.14, T.15 N., R.3 E., Marion County.
03354000	White River near Centerton, Ind., Lat 39°30'02", long 86°24'24", in SW 1/4 SE 1/4 sec.3, T.12 N., R.1 E., Morgan County.
03357000	White River at Spencer, Ind., Lat 39°16'49", long 86°45'42", in NE 1/4 NE 1/4 sec.29, T.10 N., R.3 W., Owen County.
03360500	White River at Newberry, Ind., Lat 38°55'42", long 87°01'00", in NE 1/4 NE 1/4 sec.25, T.6 N., R.6 W., Greene County.
03361000	Big Blue River at Carthage, Ind., Lat 39°44'38", long 85°34'33", in SW 1/4 SW 1/4 sec.18, T.15 N., R.9 E., Rush County.
03361500	Big Blue River at Shelbyville, Ind., Lat 39°31'45", long 85"46'55", in SE 1/4 SE 1/4 sec.31, T.13 N., R.7 E., Shelby County.
03363000	Driftwood River near Edinburg, Ind., Lat 39°20'21", long 85°59'11", in NW 1/4 SW 1/4 sec.4, T.10 N., R.5 E., Bartholomew County.
03364000	East Fork White River at Columbus, Ind., Lat 39°12'00", long 85°55'32", in NE 1/4 NW 1/4 sec.25, T.9 N., R.5 E., Bartholomew County.
03371500	East Fork White River near Bedford, Ind., Lat 38°46'10", long 86°24'30", in SW 1/4 NE 1/4 sec.21, T.4 N., R.1 E., Lawrence County.
03373500	East Fork White River at Shoals, Ind., Lat 38°40'02", long 86°47'32", in SW 1/4 NW 1/4 sec.30, T.3 N., R.3 W., Martin County.

Table 1.--Location of U.S. Geological Survey gaging stations--Continued

Number	Station Name
03374000	White River at Petersburg, Ind., Lat 38°30'39", long 87°17'22", in SE 1/4 SW 1/4 sec.5, T.1 N., R.8 W., Pike County.
04178000	St. Joseph River near Newville, Ind., Lat 41°23'08", long 84°48'06", in SW 1/4 SW 1/4 sec.18, T.5 N., R.1 E., Defiance County, Ohio.
04179500	Cedar Creek at Auburn, Ind., Lat 41°21'57", long 85°03'08", in NE 1/4 NW 1/4 sec.32, T.34 N., R.13 E., Dekalb County.
04180000	Cedar Creek near Cedarville, Ind., Lat 41°13'08", long 85°04'35", in NW 1/4 NW 1/4 sec.19, T.32 N., R.13 E., Allen County.
04181500	St. Marys River at Decatur, Ind., Lat 40°50'55", long 84°56'16", in SW 1/4 SW 1/4 sec.27, T.28 N., R.14 E., Adams County.
04182000	St. Marys River near Fort Wayne, Ind., Lat 40°59'16", long 85°06'03", in A. LaFontaine Res., T.29 N., R.12 E., Allen County.
04183000	Maumee River at New Haven, Ind., Lat 41°05'06", long 85°01'20", in SE 1/4 NE 1/4 sec.2, T.30 N., R.13 E., Allen County.

Table 2.--Discharge and watershed characteristics--tributary reaches

Stream	Reach from	Reach to	Gaging station	Average discharge (ft^3/s)	Slope (ft/mi)	Length (mi)	Drainage area (mi^2)	Velocity of peak at percent of average discharge (mi/h) 25	50	100	200
Whitewater R	I-70	USGS gage at Brookville	03275000	531	6.80	50.6	529	0.52	0.79	1.11	1.61
EF Whitewater R	Dam	Beelor Rd	03275500	115	10.3	5.8	121	.37	.62	1.04	1.71
Do	Beelor Rd	SR 44	03275600	217	6.13	12.4	200	.38	.58	.89	1.38
Whitewater R	USGS gage at Brookville	Harrison, O.	03276500	1,247	4.80	21.4	1,224	.75	1.07	1.53	2.17
Wabash R	New Corydon	Linn Grove	03322500	181	1.02	21.6	262	.25	.37	.53	.78
Do	Linn Grove	Bluffton	03322900	319	1.30	11.3	453	.32	.46	.64	.90
Do	Bluffton	Wabash	03325000	574	3.43	46.8	721	.46	.71	.95	1.30
Eel R	Whitley Co Rd 260 W	Miami Co Rd 500 E	03328000	343	2.11	38.8	417	.40	.60	.93	1.38
Do	Miami Co Rd 500 E	US 24 and 35	03328500	711	3.17	31.3	789	.42	.64	1.01	1.57
Tippecanoe R	Fox Farm Rd	Marshall Co Rd 18 E (upstream site)	03330500	95.6	1.77	18.8	113	.25	.39	.61	.96
Do	Marshall Co Rd 18 E (upstream site)	SR 16 and 39	03331500	779	1.46	85.9	856	.61	.80	1.07	1.44
Wildcat Cr	Kokomo	Burlington	03333700	222	3.50	22.3	242	.45	.57	.75	1.00
Do	Burlington	Wolf Rd (Heath)	03334000	333	3.82	28.1	396	.38	.56	.73	.96
SF Wildcat Cr	Tippecanoe Co Rd 5 S	Carey Camp	03334500	229	6.29	11.0	243	.56	.81	1.13	1.57

Table 2.--Discharge and watershed characteristics--tributary reaches--Continued

Stream	Reach from	Reach to	Gaging station	Average discharge (ft³/s)	Slope (ft/mi)	Length (mi)	Drainage area (mi²)	Velocity of peak at percent of average discharge (mi/h) 25	50	100	200
Wildcat Cr	Wolf Rd (Heath)	USGS gage nr Lafayette	03335000	699	4.88	13.4	794	.50	.72	1.06	1.48
Sugar Cr	US 231	Davis bridge	03339500	426	6.91	11.7	509	.65	.94	1.33	1.91
Do	Davis bridge	Lafayette Rd	03340000	624	3.73	26.8	670	.68	1.05	1.62	2.45
White R	US 27 (Winchester)	Anderson	03347000	203	3.98	55.5	241	.24	.37	.59	.90
Do	Anderson	Noblesville	03348000	367	3.08	29.9	406	.48	.58	.85	1.24
Do	Noblesville	Nora	03349000	793	1.67	15.6	858	.41	.64	.93	1.56
Do	Nora	USGS gage at Indpls	03351000	1,053	3.04	17.3	1,219	.15	.24	.39	.71
Big Blue R	SR 3	SR 9	03361000	189	4.80	45.3	184	.35	.56	.89	1.42
Do	SR 9	Edinburg	03361500	448	4.45	25.0	421	.36	.62	.85	1.47
Driftwood R	Edinburg	USGS gage at Columbus	03363000	1,100	2.50	14.4	1,060	.51	.72	1.00	1.56
St. Joseph R	USGS gage nr Newville	Cedarville Reservoir	04178000	489	1.30	21.6	615	.34	.53	.83	1.32
Cedar Cr	Dekalb Rd 24	Cedar Chapel bridge	04179500	67.1	5.00	14.6	87.3	.26	.44	.75	1.17
Do	Cedar Chapel bridge	SR 1	04180000	229	3.87	13.1	270	.40	.60	.85	1.31
St. Marys R	NY,Chi, and St. L RR	Scheiman bridge	04181500	478	1.04	18.2	621	.34	.46	.68	1.07
Do	Scheiman bridge	Spy run	04182000	550	.92	21.7	762	.36	.49	.76	1.23

Table 3.--Discharge and watershed characteristics--main-stem reaches

Stream	Reach from	Reach to	Gaging station	Average discharge (ft^3/s)	Slope (ft/mi)	Length (mi)	Drainage area (mi^2)	Velocity of peak at percent of average discharge (mi/h) 25	50	100	200
Wabash R	Wabash	Peru	03325000	1,450	1.36	16.7	1,768	0.67	0.99	1.49	2.17
Do	Peru	Logansport	03327500	2,289	1.90	16.8	2,686	.65	1.12	1.47	2.10
Do	Logansport	Delphi	03329000	3,213	2.33	22.9	3,779	.79	1.10	1.56	2.20
Do	Delphi	Lafayette	03329500	3,324	.71	18.9	4,072	.95	1.21	1.58	1.97
Do	Lafayette	Covington	03335500	6,242	.72	40.8	7,267	.96	1.30	1.77	2.27
Do	Covington	Montezuma	03336000	7,016	.56	31.1	8,208	.91	1.15	1.45	1.83
Do	Montezuma	Terre Haute	03340500	9,288	.89	25.6	11,118	.88	1.16	1.56	2.06
Do	Terre Haute	Riverton	03341500	10,230	.65	50.9	12,265	.81	1.13	1.57	2.21
White R	USGS gage at Indianapolis	Waverly	03353000	1,342	2.29	21.0	1,635	.65	.94	1.32	1.82
Do	Waverly	Paragon	03354000	2,239	2.10	30.5	2,444	.44	.66	.95	1.42
Do	Paragon	Worthington	03357000	2,961	1.38	46.5	2,988	.89	1.16	1.57	2.18
Do	Worthington	Petersburg	03360500	4,485	1.07	88.7	4,668	1.03	1.39	1.89	2.55
EF White R	Columbus	Azalia	03364000	1,766	2.35	11.9	1,707	.70	.99	1.24	1.65
Do	Azalia	Williams bridge[a]	03371500	3,529	1.04	102.1	3,861	.65	.94	1.34	1.91
Do	Williams bridge	SR 57	03373500	5,273	.73	76.5	4,927	.70	.99	1.37	1.94
White R	Petersburg	Hazelton	03374000	11,190	.77	27.6	11,125	1.00	1.25	1.56	1.94
Maumee R	Columbia Ave (Ft Wayne)	Indiana-Ohio State line[a]	04183000	1,478	1.36	27.4	1,967	.52	.79	1.08	1.59

[a] Velocity estimated through dam(s) in reach

White R mouth 11399
OA

*USGPO: 1976 — 653-523/62 Region 5-1