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# Traveltime and Dispersion of Contaminants in the Yampa River from Steamboat Springs to the Green River, Northwestern Colorado

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## INTRODUCTION

In the event of a hazardous material spill into a river, traveltime data for various streamflows provide valuable information about traveltime and dispersion of the hazardous material. In this report, traveltime is defined as the time it takes a contaminant particle to move between known points on a river at a constant streamflow. Peak concentration can be defined as the maximum amount of a given substance per volume of water. Streamflow traveltimes and dispersion characteristics for the Yampa River were determined by two U.S. Geological Survey studies. Bauer and others (1979) presented traveltime information for the Yampa River from Steamboat Springs to Craig, Colorado. Ruddy and Britton (1989) presented traveltime information for the Yampa River from Craig to the confluence with the Green River (fig. 1). The results of these two investigations are summarized in this report. Also presented are equations used to predict the traveltime of the leading edge and the trailing edge of a hazardous material cloud and the most probable peak concentration (Jobson, 1996). This report was prepared under the U.S. Geological Survey/ National Park Service Water-Quality Partnership.

When a hazardous material spill occurs, traveltime information can be used to answer the following questions:

- When will the peak concentration of the spill arrive at a given point in the river?
- When will the leading edge of the spill arrive at a given point in the river?
- What will the peak concentration be at a given point in the river?
- When will all of the contaminant pass a given point in the river?

## HOW TO DETERMINE ARRIVAL TIME OF PEAK CONCENTRATION

To address the questions listed above, follow these six steps:

*Step 1.*—Determine the streamflow at the location of the spill by using figure 1 and the nearest streamflow-gaging station listed in table 1. Streamflow information for the streamflow-gaging stations listed in table 1 can be obtained on the Internet:

- U.S. Geological Survey at ***http://webserver.cr.usgs.gov***
- Colorado Department of Natural Resources at ***http://www.dnr.state.co.us/water/flow***
- or by telephone—Colorado Division of Water Resources Water Talk number at **303-831-7135**

If the streamflow information for the stations listed in table 1 is unavailable from the above sources, the average monthly streamflow listed in table 2 can be used. For example, if a spill occurred in May near Maybell, Colo. (site 17), table 2 would provide the average monthly streamflow for that site, in cubic feet per second (6,280 $ft^3/s$). Because of ice effect at the streamflow-gaging stations during winter months, the streamflow data provided on the Internet and the Water Talk telephone line might be higher than the actual streamflow. The reported streamflows might then be used to estimate a faster traveltime for a winter spill, thereby providing a margin of safety.

Locate the nearest traveltime reference site upstream from the spill by using figure 1 and table 3 and the point of interest downstream.

*Step 2.*—Using the streamflow from step 1 and the sites identified in step 2, determine the traveltime of the peak concentration of the hazardous material by using table 4.

If the streamflow determined in step 1 is different from the discharge reported in table 4, interpolate between values that bracket the reported streamflow or use the higher streamflow in table 4. This approach would provide a conservative traveltime.

## HOW TO DETERMINE THE ARRIVAL OF THE LEADING EDGE

*Step 3.*—Determine the arrival time of the leading edge of the contaminant by multiplying the traveltime of the peak concentration by 0.89 (Jobson, 1996).

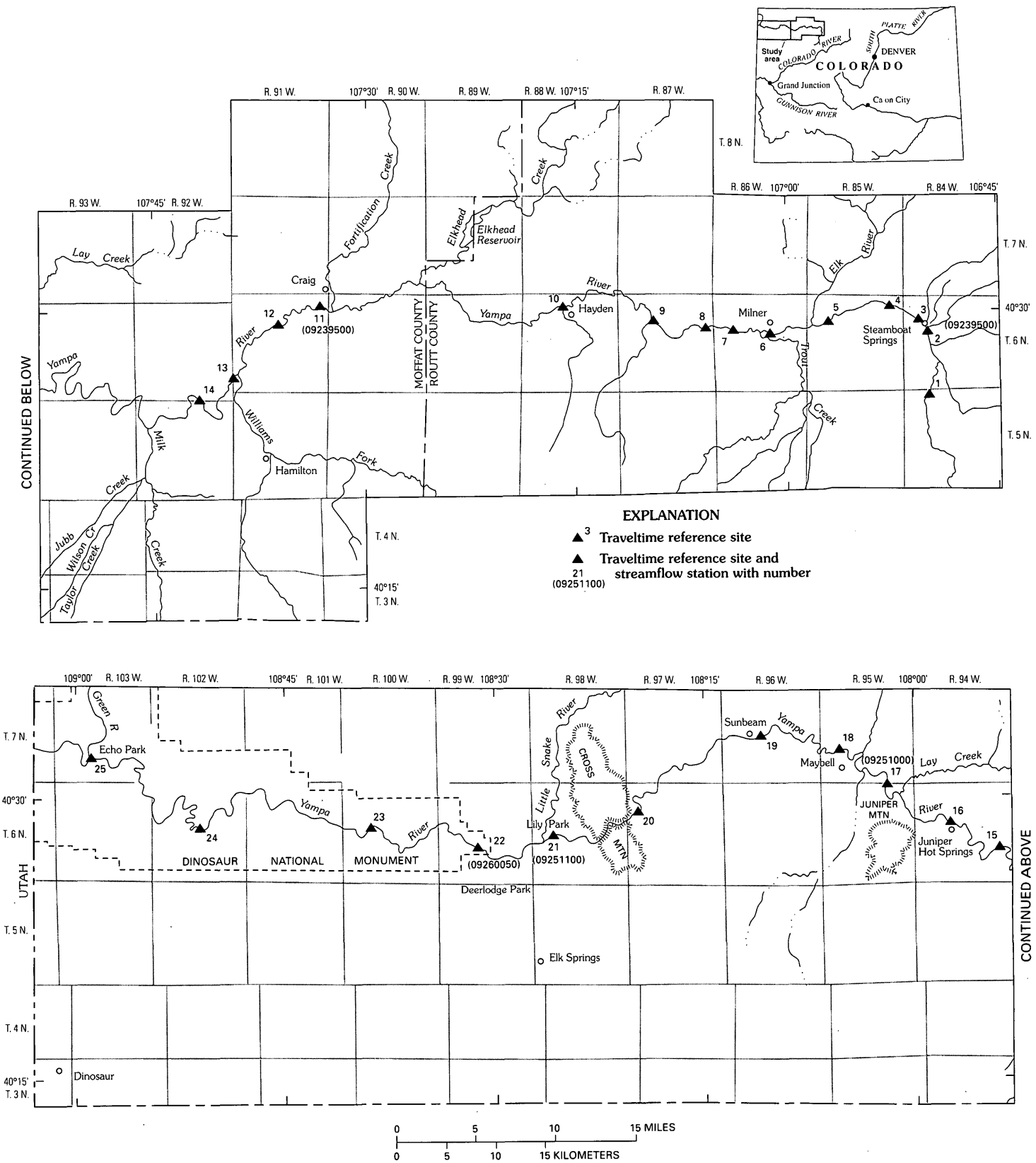


**Figure 1.** Location of traveltime reference sites within the Yampa River Basin.

**Table 1.** List of selected streamflow-gaging stations in the Yampa River Basin

| Site number (fig. 1) | Station number | Station name |
|---|---|---|
| 2 | 09239500 | Yampa River at Steamboat Springs, Colo. (Water Talk number 6*) |
| 11 | 09247600 | Yampa River below Craig, Colo. (Water Talk number 1*) |
| 17 | 09251000 | Yampa River near Maybell, Colo. (Water Talk number 12*) |
| 21 | 09251100 | Yampa River above Little Snake River, near Maybell, Colo. |
| 22 | 09260050 | Yampa River at Deerlodge Park, Colo. |

**Table 2.** Average monthly streamflow for the period of record at selected streamflow-gaging stations on the Yampa River, in cubic feet per second

[Shaded areas refer to Example Exercise]

| Month | Site 2 | Site 11 | Site 17 | Site 21 | Site 23 |
|---|---|---|---|---|---|
| January | 995 | 230 | 274 | 398 | 417 |
| February | 102 | 291 | 331 | 408 | 584 |
| March | 166 | 787 | 706 | 1,280 | 1,470 |
| April | 659 | 2,380 | 2,610 | 3,290 | 3,800 |
| May | 1,730 | 4,870 | 6,280 | 9,420 | 8,550 |
| June | 1,830 | 4,260 | 5,590 | 7,960 | 7,500 |
| July | 370 | 1,080 | 1,420 | 1,680 | 1,830 |
| August | 152 | 288 | 389 | 645 | 563 |
| September | 110 | 255 | 251 | 829 | 430 |
| October | 133 | 307 | 344 | 328 | 573 |
| November | 125 | 308 | 351 | 481 | 619 |
| December | 103 | 246 | 297 | 382 | 455 |

**Table 3.** List of traveltime reference sites on the Yampa River

| Site number (fig. 1) | Distance from mouth (river miles) | Site name |
|---|---|---|
| 1 | 200.6 | Yampa River below Oak Creek, near Steamboat Springs |
| 2 | 195.6 | Yampa River at Steamboat Springs (station 09239500) |
| 3 | 194.4 | Yampa River above wastewater-treatment plant, below Steamboat Springs |
| 4 | 191.8 | Yampa River below KOA campground, near Steamboat Springs |
| 5 | 188.5 | Yampa River above Elk River, near Milner |
| 6 | 184.1 | Yampa River at Milner |
| 7 | 182.4 | Yampa River below Trout Creek, at Milner |
| 8 | 179.7 | Yampa River below Tow Creek oilfield, near Milner |
| 9 | 174.3 | Yampa River below diversion, near Hayden |
| 10 | 164.7 | Yampa River at Hayden |
| 11 | 142.4 | Yampa River at old State Highway 13 bridge, at Craig |
| 12 | 137.4 | Yampa River at new State Highway 13 bridge, downstream from Craig (station 09247600) |
| 13 | 132.2 | Yampa River 0.25 mile downstream from the Williams Fork |
| 14 | 125.3 | Yampa River 1.90 miles downstream from Ralston Draw |
| 15 | 99.8 | Yampa River at Government Bridge |
| 16 | 93.9 | Yampa River at Juniper Hot Springs, downstream from bridge |
| 17 | 86.4 | Yampa River at U.S. Highway 40 bridge near Maybell (station 09251000) |
| 18 | 79.0 | Yampa River at county bridge 1.3 miles north of Maybell |
| 19 | 70.7 | Yampa River at bridge upstream from Sunbeam |
| 20 | 58.3 | Yampa River at mouth of Cross Mountain Canyon |
| 21 | 51.1 | Yampa River at bridge near Lily Park on Tuttle Ranch (station 09251100) |
| 22 | 46.2 | Yampa River at Deerlodge Park (station 09260050) |
| 23 | 36.1 | Yampa River at Tepee Rapids Campground |
| 24 | 19.3 | Yampa River at Harding Hole |
| 25 | 0.0 | Yampa River at mouth at Echo Park |

**Table 4.** Traveltime of peak concentrations between reference sites within the Yampa River Basin at various streamflows

[Time, hours; --, not applicable; shaded areas refer to Example Exercise]

| Site number (fig. 1, table 3) | Discharge, in cubic feet per second | | | | | |
|---|---|---|---|---|---|---|
| | 100 | | 300 | | 500 | |
| | Time between sites | Cumulative time | Time between sites | Cumulative time | Time between sites | Cumulative time |
| **Use the following sites for spills occurring *upstream* from Craig, Colo.** | | | | | | |
| 1 | -- | -- | -- | -- | -- | -- |
| 2 | 4.4 | 4.4 | 2.4 | 2.4 | 1.8 | 1.8 |
| 3 | 2.4 | 6.8 | 1.1 | 3.5 | 0.6 | 2.4 |
| 4 | 5.0 | 11.8 | 2.7 | 6.2 | 2.4 | 4.8 |
| 5 | 6.0 | 17.8 | 2.6 | 8.8 | 2.1 | 6.9 |
| 6 | 5.5 | 23.3 | 4.0 | 12.8 | 3.0 | 9.9 |
| 7 | 3.5 | 26.8 | 2.0 | 14.8 | 1.0 | 10.9 |
| 8 | 4.0 | 30.8 | 2.0 | 16.8 | 2.0 | 12.9 |
| 9 | 8.0 | 38.8 | 4.0 | 20.8 | 3.0 | 15.9 |
| 10 | 25.0 | 63.8 | 13.0 | 33.8 | 9.5 | 25.4 |
| 11 | 56.0 | 119.8 | 29.0 | 62.8 | 20.0 | 45.4 |
| **Use the following sites for spills occurring *downstream* from Craig, Colo.** | | | | | | |
| 12 | -- | -- | -- | -- | -- | -- |
| 13 | 12.0 | 12.0 | 7.0 | 7.0 | 5.5 | 5.5 |
| 14 | 17.0 | 29.0 | 10.5 | 17.5 | 8.25 | 13.75 |
| 15 | 68.0 | 97.0 | 36.0 | 53.5 | 29.0 | 42.75 |
| 16 | 12.0 | 109.0 | 10.0 | 63.5 | 7.0 | 49.75 |
| 17 | 15.0 | 124.0 | 10.0 | 73.5 | 10.0 | 59.75 |
| 18 | 27.0 | 151.0 | 14.0 | 87.5 | 11.0 | 70.75 |
| 19 | 13.0 | 164.0 | 11.0 | 98.5 | 9.0 | 79.75 |
| 20 | 35.0 | 199.0 | 15.0 | 113.5 | 15.0 | 94.75 |
| 21 | 40.0 | 239.0 | 25.0 | 138.5 | 20.0 | 114.75 |
| 22 | 15.0 | 254.0 | 9.5 | 148.0 | 7.5 | 122.25 |
| 23 | 22.0 | 276.0 | 13.5 | 161.5 | 10.5 | 132.75 |
| 24 | 29.0 | 305.0 | 17.5 | 179.0 | 14.0 | 146.75 |
| 25 | 49.0 | 354.0 | 25.5 | 204.5 | 21.0 | 167.75 |

**Table 4.** Traveltime of peak concentrations between reference sites within the Yampa River Basin at various streamflows—Continued

[Time, hours; --, not applicable; shaded areas refer to Example Exercise]

| Site number (fig. 1, table 3) | Discharge, in cubic feet per second | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1,000 | | 3,000 | | 5,000 | | 10,000 | |
| | Time between sites | Cumulative time | Time between sites | Cumulative time | Time between sites | Cumulative time | Time between sites | Cumulative time |
| **Use the following sites for spills occurring *upstream* from Craig, Colo.** | | | | | | | | |
| 1 | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | 1.3 | 1.3 | 0.6 | 0.6 | -- | -- | -- | -- |
| 3 | 0.6 | 1.9 | 0.3 | 0.9 | 0.2 | 0.2 | 0.2 | 0.2 |
| 4 | 1.2 | 3.1 | 0.8 | 1.7 | 0.6 | 0.8 | 0.3 | 0.5 |
| 5 | 1.8 | 4.9 | 0.7 | 2.4 | 0.5 | 1.3 | 0.4 | 0.9 |
| 6 | 2.0 | 6.9 | 1.2 | 3.6 | 1.0 | 2.3 | 0.6 | 1.5 |
| 7 | 0.7 | 7.6 | 0.4 | 4.0 | 0.2 | 2.5 | 0.2 | 1.7 |
| 8 | 1.1 | 8.7 | 0.7 | 4.7 | 0.6 | 3.1 | 0.4 | 2.1 |
| 9 | 2.5 | 11.2 | 1.5 | 6.2 | 1.0 | 4.1 | 0.7 | 2.8 |
| 10 | 6.0 | 17.2 | 2.6 | 8.8 | 2.1 | 6.2 | 1.2 | 4.0 |
| 11 | 14.0 | 31.2 | 7.5 | 16.3 | 5.4 | 11.6 | 3.6 | 7.6 |
| **Use the following sites for spills occurring *downstream* from Craig, Colo.** | | | | | | | | |
| 12 | -- | -- | -- | -- | -- | -- | -- | -- |
| 13 | 3.8 | 3.8 | 2.25 | 2.25 | 1.75 | 1.75 | 1.25 | 1.25 |
| 14 | 4.0 | 7.8 | 3.5 | 5.75 | 2.75 | 4.5 | 2.0 | 3.25 |
| 15 | 21.4 | 29.2 | 11.0 | 16.75 | 7.75 | 12.25 | 5.75 | 9.0 |
| 16 | 5.0 | 34.2 | 3.0 | 19.75 | 2.0 | 14.25 | 0.50 | 9.5 |
| 17 | 7.0 | 41.2 | 4.0 | 23.75 | 4.0 | 18.25 | 3.75 | 13.25 |
| 18 | 9.0 | 50.2 | 5.0 | 28.75 | 4.0 | 22.25 | 2.5 | 15.75 |
| 19 | 4.0 | 54.2 | 4.0 | 32.75 | 3.0 | 25.25 | 3.0 | 18.75 |
| 20 | 12.0 | 66.2 | 5.0 | 37.75 | 5.0 | 30.25 | 3.0 | 21.75 |
| 21 | 14.0 | 80.2 | 8.0 | 45.75 | 6.0 | 36.25 | 5.0 | 26.75 |
| 22 | 5.75 | 85.95 | 3.75 | 49.5 | 2.8 | 39.05 | 2.1 | 28.85 |
| 23 | 7.55 | 93.50 | 4.5 | 54.0 | 3.6 | 42.65 | 2.5 | 31.35 |
| 24 | 11.25 | 104.75 | 6.25 | 60.25 | 4.8 | 47.45 | 3.4 | 34.75 |
| 25 | 14.5 | 119.25 | 9.5 | 69.75 | 7.3 | 54.75 | 5.5 | 40.25 |

## HOW TO ESTIMATE THE PEAK CONCENTRATION

In order to compute the most probable peak concentration at a point downstream from a spill, it is necessary to determine (or estimate) the volume of the spill. *Please note the volume of the spill must be calculated or estimated in pounds.*

*Step 4.*—Determine the unit-concentration ($C_{up}$) from table 5 for the streamflow and sites of interest determined in steps 1 and 2.

*Step 5.*—Compute the most probable peak concentration by multiplying 0.016 times the unit-concentration value ($C_{up}$) times the volume of spill (in pounds) divided by streamflow (in cubic feet per second) (Jobson, 1996).

*Step 6.*—Compute the time the trailing edge of the spill will arrive at the downstream points of interest.

## HOW TO DETERMINE THE TRAVELTIME OF THE TRAILING EDGE

The time ($T_{d10}$) when the trailing edge of the contaminant cloud (0.1 times the peak concentration) reaches a particular point in the river can be obtained by dividing 555.6 by the unit-concentration value ($C_{up}$) obtained from table 5 (Jobson, 1996).

**Table 5.** Unit-concentration ($C_{up}$) values between reference sites on the Yampa River

[Shaded areas refer to Example Exercise]

| Site number (fig. 1, table 3) | Streamflow, in cubic feet per second | | | | | | |
|---|---|---|---|---|---|---|---|
| | 100 | 300 | 500 | 1,000 | 3,000 | 5,000 | 10,000 |
| **Use the following sites for spills occurring *upstream* from Craig, Colo.** | | | | | | | |
| 1 | -- | -- | -- | -- | -- | -- | -- |
| 2 | 275 | 471 | 609 | 812 | 1,612 | -- | -- |
| 3 | 187 | 337 | 471 | 580 | 1,125 | 4,272 | 4,272 |
| 4 | 115 | 203 | 255 | 376 | 640 | 1,249 | 1,896 |
| 5 | 79.7 | 149 | 185 | 250 | 471 | 812 | 1,125 |
| 6 | 62.8 | 107 | 134 | 185 | 329 | 490 | 715 |
| 7 | 55.5 | 93.9 | 123 | 170 | 300 | 455 | 640 |
| 8 | 49.0 | 83.9 | 106 | 150 | 260 | 376 | 531 |
| 9 | 39.9 | 69.4 | 88.1 | 120 | 203 | 293 | 411 |
| 10 | 25.7 | 45.1 | 58.2 | 82.2 | 149 | 203 | 300 |
| 11 | 14.7 | 26.1 | 34.7 | 48.5 | 86.2 | 117 | 170 |
| **Use the following sites for spills occurring *downstream* from Craig, Colo.** | | | | | | | |
| 12 | -- | -- | -- | -- | -- | -- | -- |
| 13 | 113 | 182 | 226 | 314 | 499 | 624 | 841 |
| 14 | 51.7 | 80.9 | 100 | 166 | 217 | 270 | 360 |
| 15 | 17.7 | 30.0 | 36.6 | 51.4 | 84.1 | 111 | 146 |
| 16 | 16.0 | 25.8 | 32.0 | 44.7 | 72.7 | 97.1 | 139 |
| 17 | 14.2 | 22.7 | 27.2 | 37.9 | 61.7 | 78.0 | 104 |
| 18 | 12.0 | 19.4 | 23.4 | 31.8 | 52.1 | 65.4 | 88.9 |
| 19 | 11.1 | 17.5 | 21.1 | 29.7 | 46.4 | 58.5 | 76.1 |
| 20 | 9.4 | 15.4 | 18.1 | 24.9 | 40.9 | 49.8 | 66.7 |
| 21 | 8.0 | 12.9 | 15.3 | 21.0 | 34.5 | 42.4 | 55.6 |
| 22 | 7.5 | 12.2 | 14.4 | 19.7 | 32.2 | 39.7 | 51.9 |
| 23 | 7.0 | 11.3 | 13.4 | 18.3 | 29.8 | 36.7 | 48.4 |
| 24 | 6.4 | 10.3 | 12.3 | 16.6 | 27.0 | 33.4 | 44.0 |
| 25 | 5.6 | 9.1 | 10.9 | 14.8 | 23.7 | 29.4 | 38.7 |

## EXAMPLE EXERCISE

The example form on this page can be used for the example exercise. The form can be reproduced and used in the event of a real spill.

Assume a pollutant spill of 2,000 pounds of a soluble hazardous material into the Yampa River at Steamboat Springs (site 2, fig. 1, table 3). One immediate concern would be to determine the arrival time and peak concentration of the hazardous material at the Hayden water-treatment plant, river mile 164.7 (site 10, fig. 1, table 3).

*Step 1.*—By accessing the USGS Internet address ***http://webserver.cr.usgs.gov*** (click on Colorado Water Data, Surface Water, Station number 09239500), it is determined that the discharge at streamflow-gaging station 09239500, Yampa River at Steamboat Springs (fig.1, table 1) is 1,000 cubic feet per second ($ft^3/s$).

*Step 2.*—From table 4, for a discharge of 1,000 $ft^3/s$, the traveltime of the peak concentration between sites 2 and site 10 would be 17.2 – 1.3 = 15.9 hours.

*Step 3.*—The traveltime of the leading edge of the hazardous material between site 2 and site 10 is determined by multiplying the traveltime of the peak concentration (15.9) by 0.89 = 14.2 hours.

*Step 4.*—From table 5, the unit-concentration value ($C_{up}$) is 82.2 for a streamflow of 1,000 $ft^3/s$ at site 10.

*Step 5.*—Compute the most probable peak concentration at the Hayden water plant (site 10):
0.016 times 82.2 times 2,000 pounds divided by 1,000 $ft^3/s$ = 2.63 milligrams per liter at 15.9 hours after the spill.

*Step 6.*—Compute the time the trailing edge of the spill would be expected to arrive at the water-treatment plant: Divide 555.6 by 82.2 ($C_{up}$ from step 4) = 6.8 hours after arrival of the leading edge, or 14.2 (from step 3) plus 6.8 = 21.0 hours after the spill.

All of the above computations assume there is no loss of the hazardous material between the spill and the intake. Losses could occur by chemical reactions, volatilization, adsorption on the streambed, or other processes.

**Example Form**

*Step 1*

Determine streamflow at spill location or site upstream from spill location (fig. 1, tables 1 and 3) _____ $ft^3/s$
Determine (estimate) volume of spill in pounds _____
Determine points of interest (fig. 1, table 3) _____

*Step 2*

Determine traveltime of peak concentration between points of interest (table 4) _____ hours

*Step 3*

Compute the traveltime of the leading edge of the hazardous material spill at points of interest
Traveltime of peak concentration × 0.89 = _____ hours

*Step 4*

Determine the unit-concentration value ($C_{up}$) from table 5

*Step 5*

Compute the most probable peak concentration at downstream points of interest _____
0.016 × _____ ($C_{up}$) × (Volume) / _____ ($ft^3/s$) = _____ mg/L

*Step 6*

Compute the traveltime of the trailing edge at downstream points of interest
555.6 / _____ ($C_{up}$) = _____ hours after arrival of the leading edge

## REFERENCES CITED

Bauer, D.P., Rathbun, R.E., and Lowham, H.W., 1979, Travel-time, unit-concentration, longitudinal dispersion, and reaeration characteristics of upstream reaches of the Yampa and Little Snake Rivers, Colorado and Wyoming: U.S. Geological Survey Water-Resources Investigations Report 78-122, 66 p.

Jobson, H.E., 1996, Prediction of traveltime and longitudinal dispersion in rivers and streams: U.S. Geological Survey Water-Resources Investigations Report 96-4013, 69 p.

Ruddy, B.C., and Britton, L.J., 1989, Traveltime and reaeration of selected streams in the North Platte and Yampa River Basins: U.S. Geological Survey Water-Resources Investigations Report 88-4205, 56 p.

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