This procedure provides guidance for collecting physical parameters of streams receiving effluent from a Wastewater Treatment Facility (WWTF). The data will be used to determine time of travel (TOT) using Manning's N TOT Method (see Appendix 1; Time of travel to the confluence with classified stream segment for modeling pollutant decay). Prior to conducting a TOT study the permittee will seek permission to conduct the study from the Missouri Department of Natural Resources (MDNR). Submittal of a Water Quality Review Assistance / Antidegradation Review Request form is required upon completion of the study (See Reporting section below). The purpose of each TOT study is to estimate the amount of time elapsing between effluent discharge at an outfall and its confluence with a classified water body. This data will be used to estimate pollutant decay prior to confluence with a classified water body.

General Instructions

The following instructions are for the office preparation prior to field work:

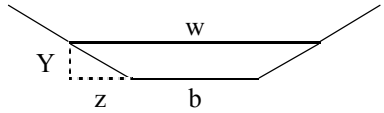
- A 7.5" topographic map will be used to identify the various stream segments to be surveyed. Changes in gradient (hypsographic lines) and confluences with other streams will be used to identify each segment. There is no maximum number of segments to evaluate; however, enough segments must be evaluated to characterize the entire length from outfall to the confluence to the first classified stream.

- The entire length of the receiving stream (from the outfall to the confluence with the first classified stream) will be surveyed. A measuring wheel, topographic and aerial photo maps, or Geographic Information Systems mapping software will be used to determine the distance (L) from the outfall to the classified stream.

- A number of representative cross-sectional transect measurements will be made within each segment. Each transect site shall be 10 times the width of the channel and contain at least one riffle-pool sequence that may or may not have water. At least two (2) cross-sections shall be measured at each site-- one riffle and one pool. The average of these cross section values at each site will represent that segment. Stream access may influence site selection; however, effort will be made to avoid measurements near bridges as these areas are not representative of the entire stream. Observation of the stream using aerial photographs or topographic maps will be used to select a site for measurement.

I. Guidance for intermittent segments having little or no flow

A trapezoid (shown below) will be used to represent the generalized cross sectional shape of the intermittent stream channel.



- For each site within the segment:
    a. The depth, or height, (Y) will be measured by running a string or measuring tape across the width (w) of the stream to the first stream terrace. This terrace will be identified by the general lack of vegetation and stream erosion. This terrace will represent a low flow. The current flow will represent a base flow. Note: Measurements should be taken after several days to a week of no rain.
    b. A tape measure and/or yard stick will be used to measure the height (Y) from the base flow level to the string. The base flow width (b) will be measured along with the first terrace stream width (w), and the difference between these two (z) will be calculated.
    c. The average values among the representative cross sectional measurements will be used in the computation of TOT for that segment.

- Cross section flow area (a) will be determined as follows: $a = (b+z)Y$

- Wet Perimeter (Pw): $b+2y(1+z^2)^{1/2}$.

- Channel slope (s) will be determined by dividing the gradient change within each segment by the length of each segment.

- Manning's roughness coefficient (n) will be determined by selecting the appropriate coefficient (n) from Table 1 in Appendix 1. Roughness must be determined in the field. Each site will have notes as to the roughness coefficient that fits best.

- Velocity (V) will be computed according to the Appendix 1.

- Tt, the time of travel for each segment, will be computed in accordance with the Appendix 1.

- The Tt's for each segment will be summed to come up with the total time of travel in days, fraction of day, or hours.

II. Guidance for segments with permanent stream flow and irregular stream channel dimensions that are closer to the classified stream

- Cross-sectional transects should be measured at intervals sufficient for characterizing the channel geometry in each segment. In general, 10-12 transects per stream mile are sufficient although the number may be considerably more or less depending on the variability of the stream channel. At a minimum, the wetted width and at least 10 depth measurements should be measured at each transect.

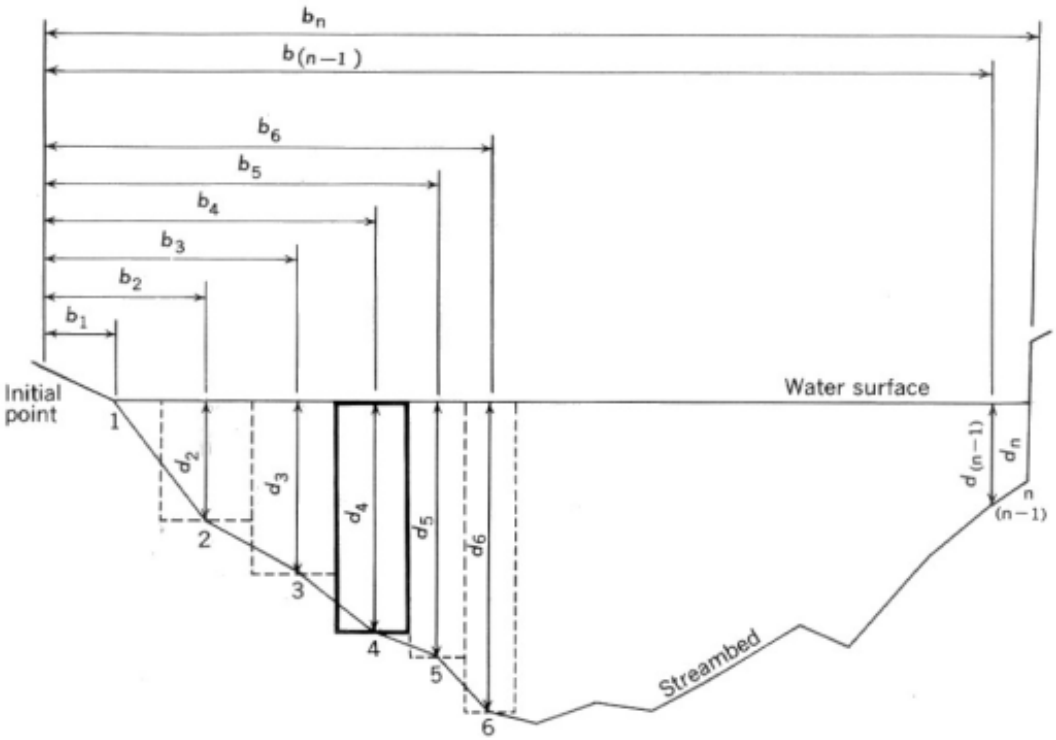
- Stretch a measuring tape across the stream cross-section. Select a regular interval, appropriate to the width of the cross-section, to take vertical depth measurements.

- Take the first tape reading at the water's edge, and record that tape reading with a depth of zero.

- Continue recording the tape readings and depths at each selected vertical. After the last vertical has been recorded, record the tape reading indicated on the tag line at the water's edge of the opposite bank, again with a depth of zero.

- To calculate width of each vertical section, subtract the value of the following vertical from the previous vertical and dividing the result by 2. The highlighted area around observation point #4 in the diagram below is an example of a vertical width.

  Example: Width (W) = $(b_5-b_3)/2$



EXPLANATION

1, 2, 3, ... n	Observation points
$b_1, b_2, b_3, \ldots\ldots b_n$	Distance, in feet, from the initial point to the observation point
$d_1, d_2, d_3, \ldots\ldots d_n$	Depth of water, in feet, at the observation point
Dashed lines	Boundary of partial sections; one heavily outlined discussed in text

- To calculate area of each vertical, multiply the width times the depth

  See figure above highlighted box #4

Example: Area (a) = $[(b_5-b_3)/2] \times d_4$

- The area of the entire cross-section is found by summing the area of each vertical section.

- Wetted perimeter of each interval may also be calculated using the width and depth readings taken instream. Wetted perimeter is the square root of [(the depth of one vertical reading – the depth of the vertical reading)^2 + (width)^2].

  Example: Wetted Perimeter (Pw) = $\sqrt{[(b_5- b_4)^2 + W^2]}$

- The wetted perimeter of the entire cross-section is found by summing the Pw of each vertical section

Reporting

A report detailing the results of the study will be submitted to the Missouri Department of Natural Resources. The report will contain, at a minimum, the following information:

- Submittal letter and a Water Quality Review Assistance / Antidegradation Review Request form.

- Topographic map(s) of the stream segments surveyed as part of the TOT study, with the permitted outfall and the confluence with the classified stream identified on the map(s).

- Results of the measurements taken during the survey.

- Calculations to determine the Tt for each segment and the total time of travel in days, fraction of day, or hours.

- Photos of the stream segments surveyed.

- Narrative summary of the survey to include prevailing weather conditions, names of surveyors, date, time, and general conditions of the stream and surround area.

Appendix 1. Time of travel to the confluence with classified stream segment for modeling pollutant decay

Manning's N Time of Travel Method

A process similar to the TR-55 method (Natural Resource Conservation Service (NRCS), *Urban Hydrology for Small Watersheds*, Technical Release No. 55, June 1986), hereafter the Manning's N Time of Travel Method, is used to compute T_c by summing all the travel times (Tt) of consecutive flow segments of the drainage conveyance system along the path extending from the hydraulically most distant point of the drainage area to the point of interest within this area.

$$T_c = Tt_1 + Tt_2 + Tt_3 + \ldots + Tt_n$$

Where:

Tt_1 = time of travel through one segment, in days

N = number of segments

Water moves through the drainage area as sheet flow, shallow concentrated flow, open channel, or a combination of these.

For the purpose of determining time of travel from the discharge point to classified stream segment, two types of flow may be possible: Shallow concentrated flow and open channel. While the shallow concentrated flow may be possible in limited circumstances, we prefer the use of the open channel flow estimation procedure due to the small size of the hydraulic radius (see open channel flow below).

Shallow Concentrated Flow

Average velocities for estimating travel time for shallow concentrated flow can be computed from the following equations. These equations can also be used for slopes **less then 0.005 ft/ft**.

$V = 16.1345(S)^{0.5}$ for unpaved surface (Equation 1)

$V = 20.3282(S)^{0.5}$ for paved surface (Equation 2)

Where:

V = average velocity, in feet per second

S = slope of hydraulic grade line (watercourse slope), in feet per foot

These two equations are based on the solution of Manning's Equation with different assumptions for "n" (Manning's roughness coefficient) and "r" (hydraulic radius, in feet). For unpaved areas "n" is 0.05 and **"r" is 0.4 feet**; for paved areas, "n" is 0.025 and "r" is 0.2 feet.

After determining average velocity, travel time for the shallow concentrated flow segment can be estimated by dividing the flow length by the velocity.

Open Channel Flow

Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on United States Geological Survey (USGS) quadrangle sheets. Manning's Equation for water surface profile information can be used to estimate average flow velocity. **Average flow velocity**

should be determined for the low-flow elevation or 7-day Q10 flow. Manning's Equation for this is:

$$V = 1.49 / n (R)^{2/3} (s)^{1/2} \qquad \text{(Equation 3)}$$

Where:

V = average velocity, in feet per second
n = Manning's roughness coefficient (see Table 1)
s = slope of the hydraulic grade line, in feet per foot
R = hydraulic radius, in feet and is defined by the equation

$$R = a/p_w \qquad \text{(Equation 4)}$$

a = cross sectional flow area, in square feet
p_w = wetted perimeter, in feet

After average velocity is computed using above equation, Tt for the channel segment can be estimated by dividing the flow length by the velocity. Velocity in channels should be calculated from Manning's Equation. Cross sections from all channels that have been field checked should be used in the calculations. This is particularly true of areas below dams or other flow control structures.

Table 1: Manning roughness coefficients, *n* — Manning's *n* range

Natural stream channels:

A. Minor streams (surface width at flood stage less than 100 ft.):

1. Fairly regular section:
   - a. Some grass and weeds, little or no brush..... 0.030-0.035
   - b. Dense growth of weeds, depth of flow materially greater than weed height 0.035-0.05
   - c. Some weeds, light brush on banks 0.035-0.05
   - d. Some weeds, heavy brush on banks..... 0.05-0.07
   - e. Some weeds, dense willows on banks 0.06-0.08
   - f. For trees within channel, with branches submerged at high stage, increase all above values by 0.01-0.02
2. Irregular sections, with pools, slight channel meander; increase values given in l (a-e) by 0.01-0.02
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:
   - a. Bottom of gravel, cobbles, and few boulders 0.04-0.05
   - b. Bottom of cobbles, with large boulders 0.05-0.07

B. Major streams (surface width at flood stage more than 100 ft.):
Roughness coefficient is usually less than for minor streams of similar description because of less effective resistance offered by irregular banks or vegetation on banks. Values of *n* may be somewhat reduced. Follow recommendation in publication cited, if possible. The value of *n* for larger streams of most regular section, with no boulders or brush, may be in the range of 0.028-0.033.

Worksheet 1: Time of Concentration (Tc) or Travel Time (Tt)

Project _____ By _____ Date _____

Location _____Checked _____ Date _____

Notes: Space for as many as two segments per flow type can be used for each worksheet.

Include a map, schematic, or description of flow segments.

Shallow concentrated flow	Segment ID_____	Segment ID_____
1. Surface description (paved or unpaved)		
2. Flow length, L……	_____ ft	_____ ft
3. Watercourse slope, s……..	_____ft / ft	_____ft / ft
4. Average velocity, V (Equation 1 or 2)……...	_____ft / s	_____ft / s
5. **Tt = L/86400V** Compute Tt…….	_____days	_____days

Open channel flow	Segment ID_____	Segment ID_____
6. Cross sectional flow area, a…….…	_____ft^2	_____ ft^2
7. Wetted perimeter, P_w……..	_____ft	_____ft
8. Hydraulic radius, **r = a/Pw,** Compute r…….	_____ft	_____ft
9. Channel slope, s……..	_____ft / ft	_____ft / ft
10. Manning's roughness coeff., n (Table 1)……..	_____	_____
11.**V = (1.49r^ 2/3 s^ 1/2)/ n,** Compute V……..	_____ft / s	_____ft / s
12. Flow length, L……	_____ft	_____ft
13. **Tt = L/86400V** …Compute Tt……	_____days	_____days

14. T_c or Tt (add Tt in steps 5 and 13)…… _____days

$$T_c = Tt_1 + Tt_2 + Tt_3 + \ldots + Tt_n$$