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Time-of-Travel Studies in Freshwater Using a Dye Tracer

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Purpose of this Document

The Washington State Department of Ecology develops Standard Operating Procedures (SOPs) to document agency practices related to sampling, field and laboratory analysis, and other aspects of the agency's technical operations.

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9/4/08	V.0	New		Jim Carroll
9/21/12	V2.0	Updating sections; 3-year review.	3.15, 6.2.1.3, 6.2.1.7, 6.3.2,6.3.5.4	Jim Carroll
12/21/15	V2.1	Updating terminology, references, etc. (no substantive changes)	throughout	Jim Carroll
12/24/15	V2.1	Recertified	All	Bill Kammin
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1.0 Purpose and Scope

1.1 This document is the Environmental Assessment Program (EAP) Standard Operating Procedure (SOP) for Determining Time-of-Travel in Freshwater Streams using a Rhodamine WT Dye Tracer and a Hydrolab® meter with a Rhodamine WT Sensor. High-level dye studies can be used to estimate dispersion characteristics of streams as well as time-of-travel. This SOP is limited to procedures for low-level dye studies to estimate the travel time of water.

1.2 The information hereafter should be used for quick reference and is not a substitute for the review and study of the following USGS publication: "Measurement of Time of Travel and Dispersion in Streams by Dye Tracing" by Kilpatrick and Wilson (1989), available at http://pubs.usgs.gov/twri/twri3-a9/. This document describes both high-level and low-level dye study methodologies. Ecology's low-level dye study differs slightly from the USGS low-level dye study. The differences are outlined in this SOP. Also, the reader should refer to "Fluorometric Procedures for Dye Tracing" by Wilson et al. (1986), available at https://pubs.usgs.gov/twri/twri3-a12, for procedures for the use and measurement of dyes.

2.0 Applicability

2.1 This SOP should be followed for all time-of-travel studies using a Hydrolab® meter with a Rhodamine WT sensor in freshwater streams. It includes procedures for tracing peak concentrations of a slug injection of dye to estimate the travel time of the water. Dye studies are used to provide time-of-travel data for water quality models.

3.0 Definitions

3.1 Centroid: The weighted center of a time-concentration curve.

3.2 Dispersion: refers to the 3-dimensional mixing of solutes in a body of water.

3.3 Flow balance: The mass balance of flow, accounting for all inputs and outputs of water within a certain reach.

3.4 Fluorescence: Near-instantaneous emission of light occurring after absorption of electromagnetic energy.

3.5 High-level time-of-travel study: A high-level study measures the entire passage of the dye cloud in order to calculate the time-of-travel and dispersion of the water.

3.6 Hydrolab® meter: A multi-probe or sensors meter with data logging capabilities that is placed in the water to take in-situ readings.

3.7 Lateral mixing: Mixing of the water from one bank to the other bank.

3.8 Longitudinal: Movement of water downstream.

3.9 Low-level time-of-travel study: A low-level study only measures the peak concentration of dye in order to estimate the time-of-travel.

3.10 Slug injection: An instantaneous dump or pouring of dye into the water

3.11 Steady flow condition: A condition when the flow is not falling or rising over a period of time.

3.12 Thalweg: The center of the main body of flowing water.

3.13 Time-concentration curve: A time plot of the concentration of dye with time plotted on the x-axis and dye concentration plotted on the y-axis.

3.14 Time-of-travel: refers to the temporal longitudinal movement of water and dissolved constituents from one point to another downstream point. Time-of-travel is usually expressed as elapsed time in units of hours or days.

3.15 Rhodamine WT: a reddish-orange dye principally used for tracer studies because it does not degrade in water easily and is non-toxic at concentrations used in environmental studies. This dye is purchased by Ecology as a 20% stock solution with a specific gravity of 1.19.

4.0 Personnel Qualifications/Responsibilities

4.1 Required reading of applicable published time-of-travel methodology (listed above).

4.2 Hydrolab® users must be properly trained by a Hydrolab® custodian and be familiar with the Hydrolab® user's manuals. For information on measuring Rhodamine WT using a Hydrolab® meter, please consult the Hydrolab® manual or Hach's website at www.hydrolab.com or contact a Hydrolab® custodian.

4.3 Training for measuring streamflows, including the Standard Operating Procedures for streamflow measurements.

4.4 Training for safety procedures for work on or over the water.

5.0 Equipment, Reagents, and Supplies

5.1 Equipment

5.1.1 Hydrolab® meter fitted with a Rhodamine WT sensor.

5.1.2 Streamflow measuring equipment (velocity meter, wading rod, tape measure, etc.)

5.2 Supplies

5.2.1 Rhodamine WT dye and volume measuring apparatus.

5.2.2 Field notebook, pencil, and time piece.

6.0 **Summary of Procedure**

6.1 A time-of-travel study is simply the observation of the time required for a slug of fluorescent dye to move between sampling sites. The peak dye concentration is recorded at a downstream location by using a deployed Hydrolab® meter set to record Rhodamine WT fluorescence at regular intervals. A slug of dye is injected (dumped) into a stream at an upstream location and allowed to drift downstream to the location of the deployed Hydrolab®. The basic principle behind time-of-travel monitoring is that the time it takes for the peak dye concentration of a slug of dye to travel downstream is an estimate of the average time-of-travel for water and solutes in that body of water.

6.2 Overview of a low-level dye study.

6.2.1 The following is an overview of low-level dye study procedures (with Ecology modifications and comments in parentheses) from the USGS publication: "Measurement of Time of Travel and Dispersion in Streams by Dye Tracing" by Kilpatrick and Wilson (1989).

6.2.1.1 Conduct a dye study at a single steady flow condition. It may be desirable to conduct separate dye studies at two or more steady flow conditions. (The travel time of water is unique for each discharge flow rate in a stream. Often, several time-of-travel studies are done at different discharge flow rates to develop a time-of-travel to discharge flow relationship or to calibrate a water quality model to differing discharge flow regimes. Field investigators should check with the project manager or project modeler to determine how many time-of-travel studies to conduct and at what discharge flow levels.)

6.2.1.2 Determine discharge, perhaps at a gaging station in or near the study reach. (Even if continuous discharge gaging is available at a location on the stream, streamflow measurements should be made at the dye injection point, all interval reaches, and any tributary inputs. Note that this is different from the methodology for a low-level dye study as described in Kilpatrick and Wilson (1989). A flow balance will be needed for the time-of-travel period in order to calibrate a water quality model. Time-of-travel studies should only be done when the discharge rate in a stream is steady. The best way to check for steady flow in a stream is to check any continuous gaging stations on the stream under study. "Real-time" data at USGS sites in Washington state can be located at http://waterdata.usgs.gov/wa/nwis/rt. If there is no real-time data, then it is advisable to have knowledge of the system to select an appropriate time period when flow is relatively stable. Any long-term flow data on the stream should be reviewed to determine monthly or annual flow patterns. Obviously, avoiding storm events is recommended, but periods of high snow-melt runoff from mountainous areas can occur during hot and clear weather patterns too, thus knowledge of the specific stream is necessary.)

6.2.1.3 Measure the amount of dye to be injected. (Kilpatrick and Wilson (1989) provide calculation equations necessary to estimate the volume of dye required to meet a concentration level at a downstream site from an injection point. Mid-channel injections (into the thalweg) achieve the quickest possible complete lateral mixing. Injections from bridges are best on larger rivers.) If multiple containers of dye must be used for injection, have multiple field staff available to dump all the dye at the same time.

6.2.1.4 Measure the dye concentrations in the field. (Ecology monitors in situ Rhodamine WT dye using a Hydrolab® meter. (Figure 1). For a low-level dye study, calibration of the Hydrolab fluorescence levels to absolute Rhodamine WT concentrations is not necessary. A low-level study is only interested in the relative concentration to determine the peak concentration of the passing dye slug, not the absolute concentration.)

6.2.1.5 Measure the dye cloud long enough to be sure the true peak has passed. (The mean travel time between two locations is defined as the difference in elapsed time between the centroids of two observed time-concentration curves from those locations. For simplicity, Ecology uses the elapsed time between the peak concentrations of the two time-concentration curves. This lessens the time necessary to collect the entire time-concentration curve and usually results in small error if short reaches are employed.)

6.2.1.6 Measure the dye cloud in the center of the flow, additional lateral measurements are optional. (Deploy the Hydrolab® in a part of the stream that has representative flow; not in an eddy.)

6.2.1.7 Measure the dye cloud at one or more locations below the injection point. (Often, Ecology conducts dye studies on multiple shorter sub-reaches, deploying several Hydrolab® meters at one time. Start at downstream reaches and work upstream so as not to contaminate sub-reaches from a previous upstream dye releases. Shorter reaches result in time-of-travel data of higher resolution and also require less dye volume per injection - see precautions concerning dye concentrations during dye studies below.)

6.2.1.8 Planning and special considerations. Good time-of-travel dye studies require several elements unique to the method including: notification of sampling to proper authorities, good planning and reconnaissance of the stream, precaution to not contaminate water withdrawals, proper time recording and note-keeping, diligent care and proper deployment of Hydrolab® meters, and patience.

6.2.2 Notification of dye studies is important, because the public may view the dye cloud in the stream, become distressed, and contact local authorities. The extent of the notification process should depend on the stream and the amount of public visibility to the stream, including recreational use of the stream. In a stream with high exposure, an official public notification may include press releases, public and law-official notification, newspaper announcements, and sending notification letters to streamside residents (see Appendix A for an example of a communication strategy). Work with your project manager, unit supervisor, or communication manager on a plan of notification. Some projects have used dye studies as an opportunity for public outreach on a water quality project. At a minimum, the local sheriff or law-enforcement official and the appropriate regional Ecology spills personnel should be notified, because they would most likely be the first to receive a complaint. Dye injections can be planned for early dawn or late dusk hours when visibility of the initial dye plume will be limited.

6.2.3 Inspect injection and monitoring sites in advance for accessibility. Use maps or GIS to estimate reach lengths. Estimate the mean width, depth, and velocity of the stream for the flow regime to be measured so that preliminary calculations of minimum sub-reach length, amount of dye, and time estimates for the time-of-travel can be made. See Kilpatrick and Wilson (1989) for equations to calculate these parameters. Shorten the lengths of reaches so that large amounts of dye are unnecessary. Plan to use the minimum amount of dye necessary for detection by the Hydrolab® meter Rhodamine WT sensor (about 1 ppb or 1 ug/L). Be aware that background fluorescence in some waters may be above 1 ppb. Some staff plan for a concentration of 5 ppb at the furthest downstream measuring station to account for background fluorescence.

6.2.4 It is <u>very important</u> to be aware of any public or private water diversions that may be used for stock watering, irrigation, or public or private water supply. Rhodamine WT is non-toxic at low concentrations; however, it is important to avoid the contamination of any water withdrawals with dye concentrations greater than 10 ug/L, which is the maximum concentration level listed in USGS guidelines (Wilson et al., 1986). Therefore, reach intervals should be set to ensure that dye is injected downstream of water withdrawals or that the withdrawal points are at the end of the dyed reach.

6.2.5 It is important to accurately record the time of dye release. Watches and Hydrolab® meters must be set to the same time. Field notes must clearly and accurately record the time and location of injection points.

6.2.6 Hydrolab® sampling and deployment considerations:

6.2.6.1 For a low-level dye study, calibration of the Hydrolab® is not necessary. A high-level dye study to measure dispersion would require that dye concentration standards be made and used for calibrating the Hydrolab® sensor.

6.2.6.2 Cleaning will help ensure that the Rhodamine sensor is performing properly. During times of continuous monitoring deployments, cleaning between deployments is adequate.

6.2.6.3 High flow, turbulence, and dynamic water elevations can create challenging deployment logistics. Methods for deployment vary and will be discussed during Hydrolab® training. Basic methods are described in the Hydrolab® user's manual. Deployment requires the selection of a location that is secure but accessible and is in a part of the stream that has representative flow (not in an eddy).

6.2.6.4 For proper functioning of the Rhodamine WT sensor, Hydrolab® meters should be placed so that the Rhodamine sensor is not subjected to varying ambient light conditions. Light refraction through the rippling surface of the water can create varying ambient light conditions and compromise the meter's compensation for ambient light, which may result in inaccurate readings. It is best to place the Hydrolab® meter in a shaded section of the stream or at least orient the Hydrolab® meter so the sensor is shaded by the cage protector. Sometimes a PVC deployment tube is used to shade and secure the datalogger.

6.2.7 Patience is needed for time-of-travel studies. Estimates of the time-of-travel can be made using the guidelines in Kilpatrick and Wilson (1989), but these are only estimates and are frequently inaccurate. Bring a laptop to download data from the Hydrolab® to check if the peak of the dye slug has passed before pulling the Hydrolab®. The dye at the downstream location may no longer be visible. (It shouldn't be if a proper amount of dye was used).

6.3 Like all environmental monitoring, a Quality Assurance Project Plan (QAPP) should be developed for time-of-travel studies.

7.0 Records Management

7.1 There are no standardized recording sheets for this method. Care should be taken to record injection locations and times, field conditions, and other relevant information at frequent intervals. Follow guidelines for downloading and securing Hydrolab® continuous data files.

8.0 Quality Control and Quality Assurance

8.1 QA/QC procedures are limited for this method, other than repeating a dye study at the same flow at a different time. Proper notetaking and time recording is essential. Any other QA/QC procedures should be addressed on a project-by-project basis in the QAPP for the project.

9.0 Safety

9.1 Users of Rhodamine WT should take special precautions to avoid direct contact with the dye. Rubber gloves or plastic gloves should be worn when handling concentrated dye solutions. Immediately wash any areas that come into contact with dye.

9.2 Rhodamine WT is non-toxic at low concentrations. Humans should not be exposed to dye concentrations above 10 ug/L. Water withdrawn from the stream for any beneficial uses should not be above 10 ug/L.

9.3 All appropriate safety procedures should be followed if working on docks, bridges, or boats and when deploying and retrieving remote moorings with buoys and anchors.

9.4 Installation of mounted tubes or other deployment should follow safety procedures for use of tools and work over water.

9.5 For further field health and safety measures refer to the Environmental Assessment Program (EAP) Safety Manual (EAP, updated March 2019).

9.6 Chemical Safety Data Sheets (SDSs) for all chemicals used in the procedures outlined in this SOP can be found on EAP's SharePoint site. In addition, binders containing SDSs can be found in all field vehicles, vessels, Ecology buildings, or other locations where potentially hazardous chemicals may be handled. EAP staff that follow Ecology SOPs are required to familiarize themselves with these SDSs and take the appropriate safety measures for these chemicals.

9.7 Theft

9.7.1 Hydrolab® meters deployed in small creeks and clear rivers are easily seen. To avoid problems with theft and vandalism, hide them carefully or lock them up with cables. Deploy Hydrolab® meters upstream or downstream of public access areas, private property, or places where boaters and swimmers can see them. Under overhanging vegetation or behind instream rocks and fallen trees are often good places to hide them, as long as water circulation is not limited.

9.7.2 Do not use large floats or anchors in smaller streams; they attract attention. Instead, note where the Hydrolab® meter is and cover it as much as possible. Small cement blocks work well as anchors. If the Hydrolab® meter is deployed in a large river, floats, line, and larger anchors may be necessary. Consult an experienced Hydrolab® user for further details.

9.7.3 If you cannot find a Hydrolab® meter and suspect theft is the cause, visit the local police station and fill out a report. Ecology has located lost equipment by running ads in local papers.

10.0 References

10.1 Environmental Assessment Program, 2019. Environmental Assessment Program Safety Manual. Updated March 2019. Washington State Department of Ecology. Olympia, WA.

10.2 Hach Environmental. 2015. Hydrolab® Homepage. www.hydrolab.com. Viewed December 21, 2015.

10.3 Kilpatrick, F.A., and J.F. Wilson, Jr., 1989. "Measurement of Time of Travel and Dispersion in Streams by Dye Tracing," Chapter A9, Book 3: *Applications of Hydraulics, Techniques of Water-Resources Investigations of the United States Geological Survey*, United States Government Printing Office, Washington: 1989

10.4 Wilson, J.F., Jr., E.D. Cobb, and F.A. Kilpatrick, 1986. "Fluorometric Procedures for Dye Tracing," Chapter A12, Book 3: *Applications of Hydraulics, Techniques of Water-Resources Investigations of the United States Geological Survey, United States Government Printing Office*, Washington: revised 1986