Review of Flow Duration Methods and Indicators of Flow Duration in the Scientific Literature: Northeast and Southeast of the United States

March 2022

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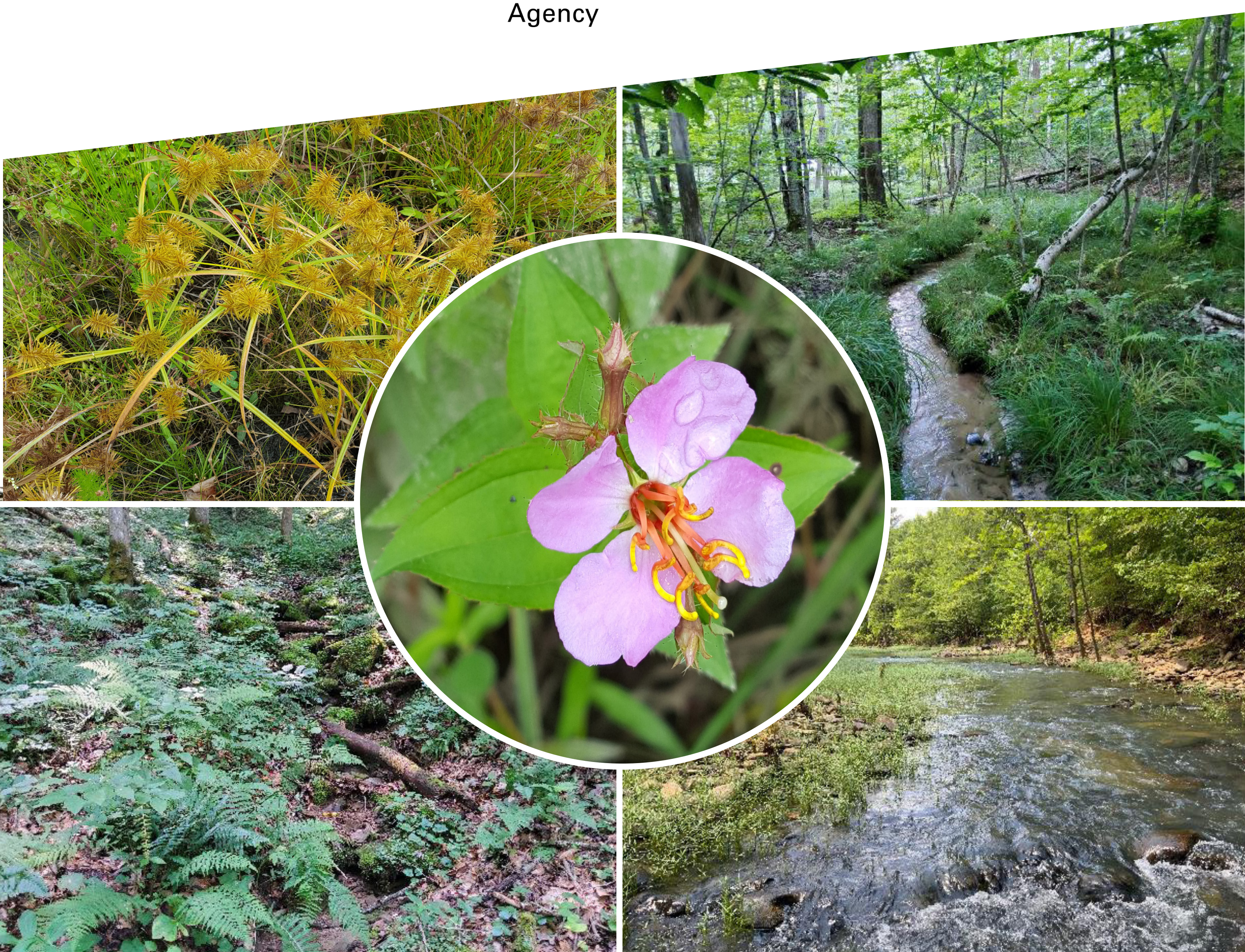
United States Environmental Protection Agency



Review of Flow Duration Methods and Indicators of Flow Duration in the Scientific Literature
Northeast and Southeast of the United States

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<u>Cover Photos</u>

Stream photos are the property of the U.S. Environmental Protection Agency and were taken as part of data collection efforts for development of a Streamflow Duration Assessment Method in the Northeast-Southeast.

Cyperus sp. (flatsedge), Yadkin County, NC: courtesy of Amy James

Rhexia sp. (meadow beauty), Yadkin County, NC: courtesy of Amy James

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1.0 STATEMENT OF THE PURPOSE

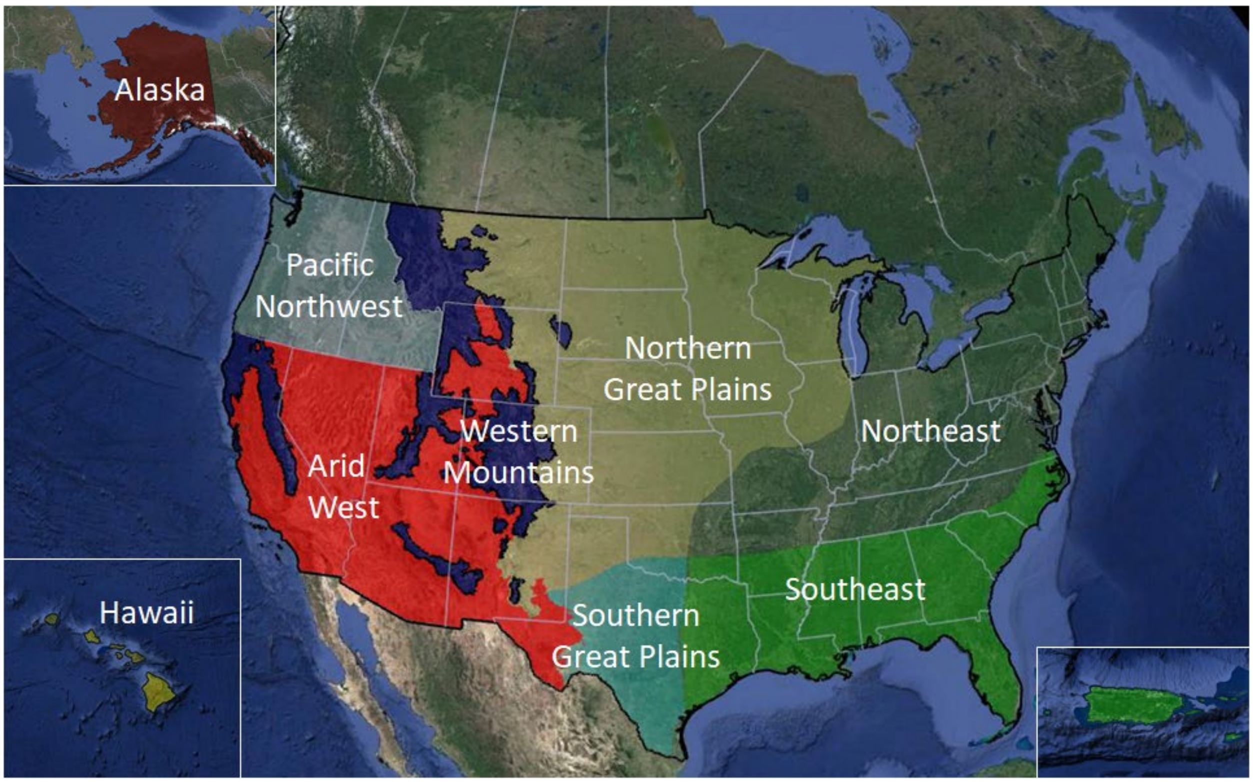
The primary purpose of this review is to document methods and indicators that may be used to develop a streamflow duration assessment method (SDAM) for the north- and southeast (NE and SE, respectively) regions of the U.S. (including Puerto Rico and the U.S. Virgin Islands), with an emphasis on field-based methods that distinguish ephemeral from perennial and intermittent streams. It will present indicators proposed for testing at both baseline and validation sites across the NE/SE, following the process of Fritz et al. (2020). Additionally, information on potential study sites of known hydrology will be included, as gleaned from the existing literature, and from input from the Regional Steering Committee and other practitioners working in the NE/SE, where possible. Results of literature screened for this purpose can be found in Appendix A.

This work is part of a larger effort by the U.S. Environmental Protection Agency, working cooperatively with the U.S. Army Corps of Engineers, to develop regional SDAMs for nationwide coverage (https://www.epa.gov/streamflow-duration-assessment).

Although direct measures of flow duration (e.g., long-term records from stream gauges) are usually preferred to determine whether a stream is perennial, intermittent, or ephemeral, indirect indicators of hydrology can also be used for this purpose when direct measures are unavailable or impractical to deploy (Fritz et al. 2020). Indirect indicators are generally those which are shaped by the typical hydrology of the channel, such as its geomorphology (e.g., presence of bed and bank, channel depositional features, or riffle-pool sequences), associated biology (e.g., presence and type of macroinvertebrates or presence of wetland plants), and other hydrology indicators aside from the presence of flowing water (e.g., presence of hydric soils or sediment on plants and debris). Indirect flow duration indicators have two major strengths that make them effective tools for those assessing potentially regulated waters and aquatic resource managers. First, they are substantially less expensive to measure, typically requiring little more than a single site-visit, whereas stream gauges require substantial installation and maintenance costs. Second, many indirect indicators reflect long-term hydrologic characteristics, integrating over space and time; thus, they provide better information about flow duration than instantaneous or short-term observations of hydrology, which may be absent during drier periods that may not reflect typical reach conditions (i.e., drought conditions).

The NE, within the context of this review, is considered those areas dominated by forest-type vegetation where snowmelt contributes at least some flow to streams and rivers during the year. Average yearly precipitation ranges widely from approximately 25 (northeast Michigan) to 100 inches (southwest North Carolina), but most areas receive between 40 and 50 inches of precipitation a year, on average. States within (or partially within) this region include Connecticut, Indiana, Kentucky, Maine, Maryland, Massachusetts, New Hampshire, New York, Ohio, Pennsylvania, Rhode Island Tennessee, Vermont, Virginia, and West Virginia, as well as portions of Arkansas, Illinois, Michigan, Missouri, North Carolina, and Oklahoma (Figure 1).

The SE, within the context of this review, is considered those areas characterized by forest-type vegetation that are generally dominated by diverse types of rainfall runoff rather than snowmelt, including tropical storms and hurricanes. Average yearly precipitation ranges widely from approximately 35 (east Texas) to over 150 inches (mountainous areas of Puerto Rico), but most areas receive between 50 and 60 inches of precipitation a year, on average. States and territories within (or partially within) this region include Alabama, Georgia, Florida, Louisiana, Mississippi, Puerto Rico, South Carolina, and the U.S. Virgin Islands, as well as portions of Arkansas, North Carolina, Oklahoma, and Texas. (Figure 1).



2.0 METHODS

2.1 General approach

To date, three regions have had flow duration literature reviews completed: the Arid West (AW; McCune and Mazor 2019), the Western Mountains (WM; McCune and Mazor 2021), and the northern and southern Great Plains (GP; James et al. 2022). For this literature review, existing flow duration assessment methods, data sources, and indicators identified in these previous literature reviews were reevaluated for their applicability to the NE and SE. In addition, further queries of literature databases were conducted to identify and evaluate any additional flow duration methods, data sources, and indicators that should be considered specifically for the NE and SE.

As with the AW, WM, and GP regions, field indicators of flow duration were first identified from established flow duration methods (Figure 2). Indicators were characterized by type (e.g., plants, benthic macroinvertebrates) and endpoint used to assess the indicator (e.g., presence of indicator taxa, abundance). This initial set was supplemented with additional indicators whose use was supported by scientific literature and other appropriate sources but were not incorporated into established methods. The full list of potential indicators was then evaluated for a number of key criteria:

Consistency: Does it work? Is there evidence from appropriate sources (see below) that the indicator can discriminate flow classes across different environmental settings, seasons, etc.? Indicators were consistent if it was used in at least two methods or showed support as a discriminatory tool in the scientific literature.

Repeatability: Can different practitioners take similar measurements, with sufficient training and standardization? Is the indicator robust to sampling conditions (e.g., time of day)? Repeatability was assessed based on the authors' personal knowledge of field methods used to determine flow duration.

Defensibility: Does the indicator have a rational or mechanistic relationship with flow duration in the region being considered? For example, hydric soils develop in the anoxic conditions created during prolonged inundation and therefore are unlikely to be found in ephemeral streams (Cowardin et al. 1979). In contrast, substrate sorting reflects the magnitude of flow (Hassan et al. 2006), and sorting is evident in ephemeral, as well as perennial and intermittent streams.

Rapidness: Can the indicator be measured during a one-day site-visit (even if subsequent lab analyses are required)? Methods requiring multi-day visits are outside the goals of the present study.

Objectivity: Does the indicator rely on objective (often quantitative) measures? Or does it require extensive subjective interpretation by the practitioner?

For each indicator, it was also noted if there were studies demonstrating efficacy of the indicator in determining flow-duration classes, if available.

The list of potential indicators was shortened to a list of priority indicators for further evaluation if they met most of these criteria. This list was further evaluated for two additional desirable (but not essential) criteria:

Robustness: Does human activity complicate interpretation of the indicator in highly disturbed or managed settings? For example, aquatic vegetation may be purposefully eliminated from streams managed as flood control channels, limiting the value of vegetation indicators in certain environments. Although many indicators can be influenced by human activity, they may still provide value in determining flow class (particularly in undisturbed streams). Therefore, this was considered an important, but non-essential, criterion for selecting indicators for exploration.

Practicality: Can the technical team realistically sample the indicator in the present study? For example, if special permits are required for assessment, an indicator may be inappropriate for further investigation.

Based on these criteria, a final list of possible indicators of flow duration were selected to serve as the basis for field data collection in the NE and SE. The objective here is to identify indicators that can be combined and evaluated as a SDAM for the NE/SE region. A subsequent objective is to determine how well the preliminary SDAM works compared to Nadeau (2015) and the method developed by the North Carolina Division of Water Quality (NCDWQ 2010).

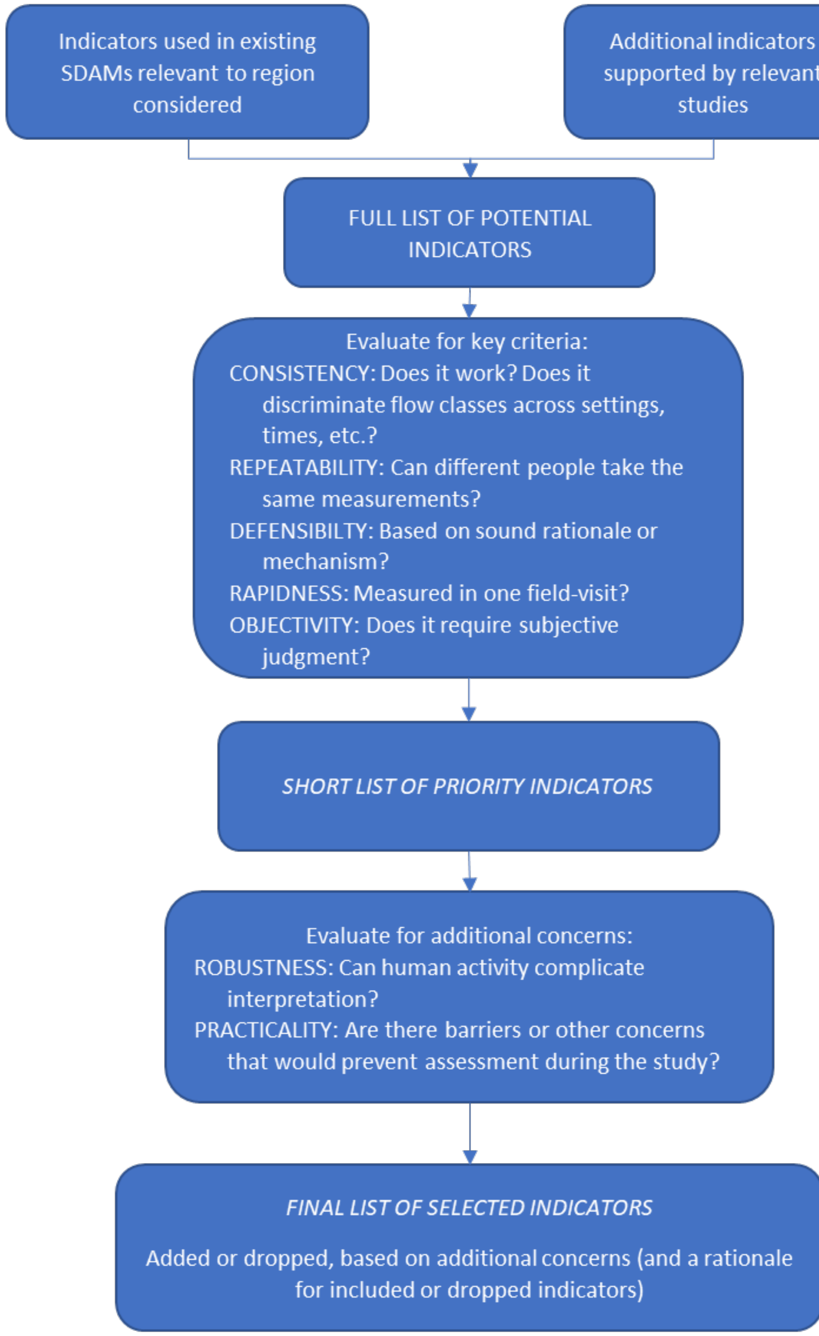


Figure 2. Process for identifying indicators of flow duration.

2.2 Search methods

First, sources identified in the AW, WM, and GP literature reviews were evaluated for their relevance to the NE/SE. These included flow duration methods from across the U.S. and elsewhere, data sources that could be more broadly applied across regions, and sources with data specific to the NE/SE. These sources have already been evaluated using the decision tree shown in Figure 3 for the AW, WM, and/or GP literature reviews. Therefore, no further analysis was performed on these sources, unless they had information specific to the NE/SE.

To compile a more thorough collection of NE/SE-specific flow duration sources, additional searches of reference libraries and search engines, including Google, Google Scholar, and Web of Science (WOS), were completed. Search engines other than WOS were used for comparison, but their results were not appreciably different or did not provide results as comprehensive as WOS. Dates of search, search terms and combinations, and number of hits for each are shown in Table 1. If the number of hits was large, only the titles or abstracts of the first 50 search results were reviewed to determine applicability to subject and the NE/SE. This compiled library was also supplemented by appropriate sources from the personal libraries of the technical team, and input from members of the NE and SE Regional Steering Committees.

Table 1. Search parameters and dates used to assemble literature on indicators of flow duration in the NE/SE.

Search Source	Search Date	Key Terms	Hits
WOS	2/21/20	"New England" AND ("perennial stream" OR "intermittent stream" OR "ephemeral stream" OR "dry stream" OR " interrupted stream" OR "seasonal stream" OR "temporary stream" OR "episodic stream" OR " flow permanence" OR " intermittency")	9
WOS	2/21/20	"northeast" AND ("perennial stream" OR "intermittent stream" OR "ephemeral stream" OR "dry stream" OR " interrupted stream" OR "seasonal stream" OR "temporary stream" OR "episodic stream" OR " flow permanence" OR " intermittency")	29
WOS	2/21/20	"southeast" AND ("perennial stream" OR "intermittent stream" OR "ephemeral stream" OR "dry stream" OR " interrupted stream" OR "seasonal stream" OR "temporary stream" OR "episodic stream" OR " flow permanence" OR " intermittency")	34
WOS	2/21/20	"Appalachian" AND ("perennial stream" OR "intermittent stream" OR "ephemeral stream" OR "dry stream" OR " interrupted stream" OR "seasonal stream" OR "temporary stream" OR "episodic stream" OR " flow permanence" OR " intermittency")	15

Search Source	Search Date	Key Terms	Hits
WOS	3/20/20	("Maine" OR "New Hampshire" OR "Massachusetts" OR "Vermont" OR "New York" OR "Connecticut" OR "Rhode Island" OR "New Jersey" OR "Pennsylvania" OR "Delaware" OR "Maryland" OR "Virginia" OR "West Virginia" OR "Ohio") AND ("perennial stream" OR "intermittent stream" OR "ephemeral stream" OR "dry stream" OR " interrupted stream" OR "seasonal stream" OR "temporary stream" OR "episodic stream" OR " flow permanence" OR " intermittency")	63
WOS	3/20/20	("North Carolina" OR "South Carolina" OR "Georgia" OR "Florida" OR "Alabama" OR "Mississippi" OR "Texas" OR "Arkansas" OR "Tennessee" OR "Oklahoma" OR "Missouri" OR "Illinois" OR "Indiana" OR "Michigan") AND ("perennial stream" OR "intermittent stream" OR "ephemeral stream" OR "dry stream" OR "interrupted stream" OR "seasonal stream" OR "temporary stream" OR "episodic stream" OR " flow permanence" OR " intermittency")	137
WOS	3/20/20	"northeastern United States" OR "southeastern United States" AND ("macroinvertebrates" OR "amphibians") AND "stream"	45
WOS	7/9/2020	("northeastern United States" OR "southeastern United States" OR "Appalachian" OR "New England" OR "northeast" OR "southeast") AND ("intermittent" OR "ephemeral" OR "wet weather conveyance" OR "stormflow channel" OR "temporary flow" OR "seasonal flow") AND "fish"	72
WOS	7/9/2020	("Maine" OR "New Hampshire" OR "Massachusetts" OR "Vermont" OR "New York" OR "Connecticut" OR "Rhode Island" OR "New Jersey" OR "Pennsylvania" OR "Delaware" OR "Maryland" OR "Virginia" OR "West Virginia" OR "Ohio") AND ("intermittent" OR "ephemeral" OR "wet weather conveyance" OR "stormflow channel" OR "temporary flow" OR "seasonal flow") AND "fish"	142

Search Source	Search Date	Key Terms	Hits
WOS	7/9/2020	("North Carolina" OR "South Carolina" OR "Georgia" OR "Florida" OR "Alabama" OR "Mississippi" OR "Texas" OR "Arkansas" OR "Tennessee" OR "Oklahoma" OR "Missouri" OR "Illinois" OR "Indiana" OR "Michigan") AND ("intermittent" OR "ephemeral" OR "wet weather conveyance" OR "stormflow channel" OR "temporary flow" OR "seasonal flow") AND "fish"	337
WOS	7/9/2020	("northeastern United States" OR "southeastern United States" OR "Appalachian" OR "New England") AND ("reptile" OR "amphibian" OR "frog" OR "salamander" OR "turtle" OR "snake") AND ("water quality" OR "sediment transport" OR "best management practices" OR "pesticide" OR "herbicide" OR "organic matter" OR "nitrogen" OR "phosphorous" OR "biogeochemistry" OR "DOC")	30
WOS	7/9/2020	("Maine" OR "New Hampshire" OR "Massachusetts" OR "Vermont" OR "New York" OR "Connecticut" OR "Rhode Island" OR "New Jersey" OR "Pennsylvania" OR "Delaware" OR "Maryland" OR "Virginia" OR "West Virginia" OR "Ohio") AND ("reptile" OR "amphibian" OR "frog" OR "salamander" OR "turtle" OR "snake") AND ("water quality" OR "sediment transport" OR "best management practices" OR "pesticide" OR "herbicide" OR "organic matter" OR "nitrogen" OR "phosphorous" OR "biogeochemistry" OR "DOC")	203
WOS	7/9/2020	("North Carolina" OR "South Carolina" OR "Georgia" OR "Florida" OR "Alabama" OR "Mississippi" OR "Texas" OR "Arkansas" OR "Tennessee" OR "Oklahoma" OR "Missouri" OR "Illinois" OR "Indiana" OR "Michigan") AND ("reptile" OR "amphibian" OR "frog" OR "salamander" OR "turtle" OR "snake") AND ("water quality" OR "sediment transport" OR "best management practices" OR "pesticide" OR "herbicide" OR "organic matter" OR "nitrogen" OR "phosphorous" OR "biogeochemistry" OR "DOC")	478
GS	3/26/20	"northeastern United States" AND "flow duration"	431

Search Source	Search Date	Key Terms	Hits
GS	3/26/20	“southeastern United States” AND “flow duration”	591
GS	3/26/20	“northeastern United States” AND “stream” AND (“perennial” OR “intermittent” OR “ephemeral”)	8,700
GS	3/26/20	“southeastern United States” AND “stream” AND (“perennial” OR “intermittent” OR “ephemeral”)	12,700
GS	3/5/20	"northeastern United States" AND "flow duration" AND ("macrophytes" OR "algae" OR "bryophytes" OR “riparian vegetation”)	125
GS	3/5/20	"southeastern United States" AND "flow duration" AND ("macrophytes" OR "algae" OR "bryophytes" OR “riparian vegetation”)	201
GS	3/23/20	“intermittent stream” AND “indicator” AND “northeastern United States"	165
GS	3/23/20	“intermittent stream” AND “indicator” AND “southeastern United States"	252
GS	3/23/20	"northeastern United States" AND "flow duration" AND ("macroinvertebrates" OR "fish" OR "amphibians")	239
GS	3/26/20	"southeastern United States" AND "flow duration" AND ("macroinvertebrates" OR "fish" OR "amphibians" OR “mussels”)	329
Google	3/26/20	“northeastern United States” AND “flow duration”	8,440
Google	3/26/20	“southeastern United States” AND “flow duration”	13,500
Google	3/26/20	“northeastern United States” AND “streamflow duration” AND “indicator”	174
Google	3/26/20	“southeastern United States” AND “streamflow duration” AND “indicator”	285

2.3 Analysis of sources

2.3.1 Including Sources in the Review

Applicability/Utility: Sources with available articles were first reviewed to determine if a source was ‘applicable’ for this analysis. Applicable sources were those that provided information about the biological, physical, or hydrologic characteristics of streams along a flow duration gradient in the NE or SE. Sources in regions outside the NE/SE were also considered applicable if other elements of the reference were relevant to the study. Several sources found during searches did not meet this criterion. Factors that limited the applicability of a citation include reliance on intensive hydrologic data (e.g., continuous flow gauge data), or reliance on other data types that could not be rapidly measured in the field (e.g., model data, remote sensing inputs).

Once a source was considered applicable, it was evaluated for inclusion in this review following the decision tree in Figure 3 and as described below.

Review: Sources needed to undergo peer-review, be published by a government agency, or come from a subject-matter expert. All sources met this criterion.

Soundness: Sources needed to rely on sound scientific principles, and conclusions had to be consistent with data presented. All sources met this criterion.

Clarity/Completeness: Sources needed to provide underlying data, assumptions, or model parameters, as well as author sponsorship or author affiliations. Several sources did not provide a clear basis for determining flow-duration classes for study sites. Where possible, we applied the most appropriate flow-duration class based on available data, sometimes applying ambiguous classifications (e.g., "perennial or intermittent", or "intermittent or ephemeral"). If data were insufficient to support these designations, the source was excluded from the review.

Uncertainty/Variability: Sources needed to identify variability, uncertainties, sources of error, or bias, reflecting them in any conclusions drawn. This criterion could generally be satisfied through reported ranges or measures of variability and uncertainty (e.g., standard deviation, statistical significance) associated with each indicator and flow-duration class. No sources were excluded for this criterion.

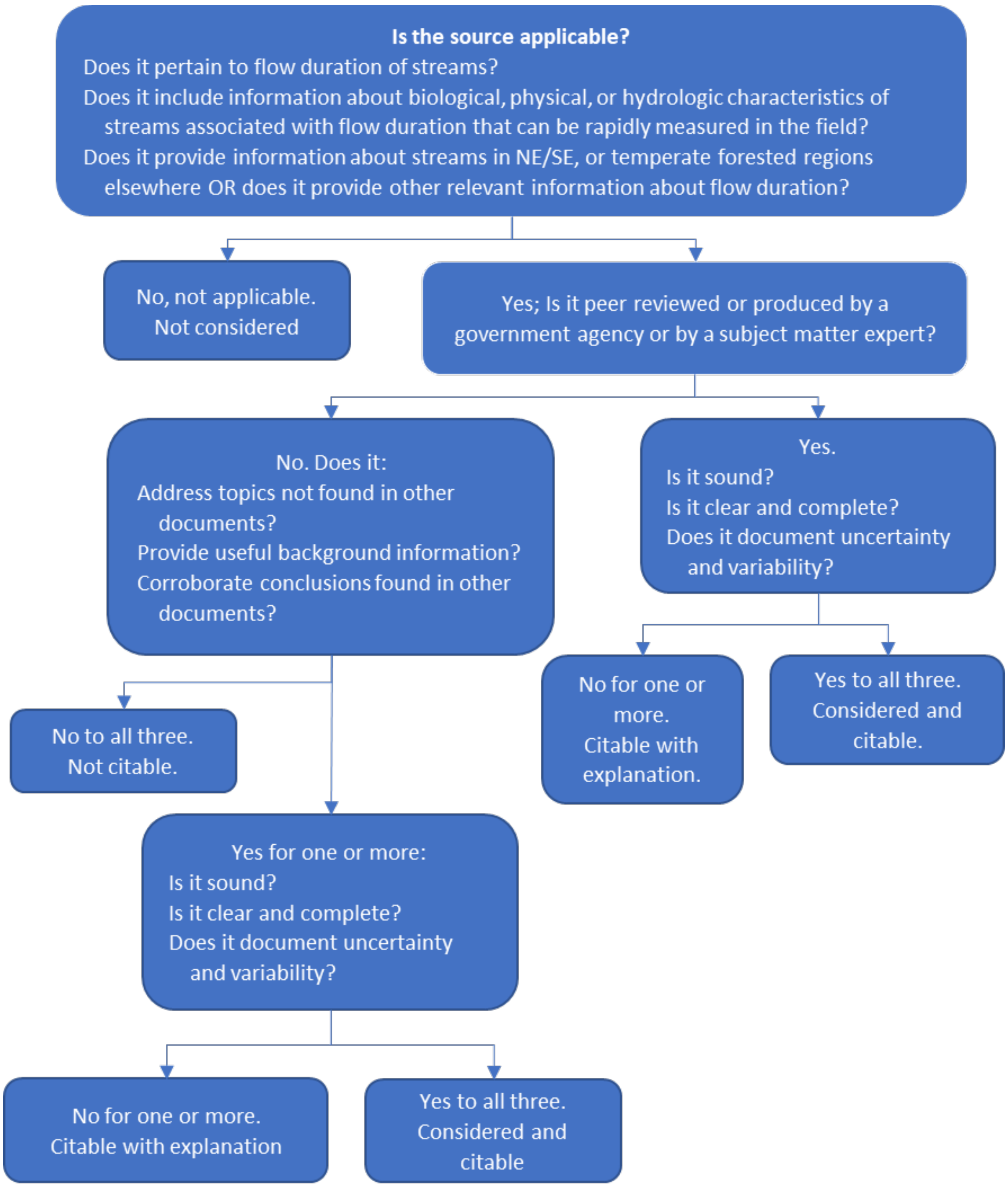


Figure 3. Decision tree for reviewing sources.

2.3.2 Evaluating information about indicators

Each source was reviewed to identify information about indicators of flow duration. First, the classes represented in the study were determined. Classes were either reported by the authors or determined from other data presented in the study. For example, sites were classified as perennial if year-round flow was reported. Where appropriate, ambiguous classes were applied; for example, if a study reported that a stream dried, but the duration of the dry period was unclear, the site was classified as “ephemeral or intermittent.” Results, including manuscript text, figures, and tables, were reviewed for information about indicators associated with different site classes. Typical levels (e.g., means) and associated measures of variability (e.g., ranges, standard deviations) were recorded for each indicator.

3.0 EXISTING FLOW DURATION ASSESSMENT METHODS

Twenty (20) total methods were found to be appropriate for evaluating flow duration classes, though two of these were from outside the U.S. Table 2 shows those methods specifically designed for use in the NE or SE (11). Two from the NE are not field methods, but primarily focus on probability modeling using regression analysis. While methods without a field component are generally outside the scope of this review, these two are included in the discussion because at least one is being used to support jurisdictional determinations. Table 4 shows methods for evaluating flow duration classes used in other regions of the U.S. or other countries (7). Methods developed for use outside the NE or SE were considered applicable because they included rapid field methods for determining streamflow classes. An additional six methods were found during the AW, WM, or GP literature searches (Kennard et al. 2010, Trubilowicz et al. 2013, Berkowitz et al. 2011, Noble et al. 2010, Berhanu et al. 2015, and Porras and Scoggins 2013), but were excluded because they lacked a rapid field component, focusing instead on long-term records of measured or modeled flow.

Table 5 provides a summary of which field indicators are used with each method, while Table 5 provides a summary of the evaluation criteria for each indicator. Indicators that met all criteria were designated as priority indicators. All priority indicators were proposed for inclusion in the NE/SE pilot study; the rationale for including non-priority indicators is provided in the table.

Table 2. Methods for assessing flow duration and their associated indicators in the NE/SE.

Source	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
NC Division of Water Quality (2010; version 4.11)	North Carolina	Yes, to comply with 401 ('waters of the state') and state-level rules (riparian buffers); used by Wilmington District Corps as supporting evidence of Waters of the US (WOUS) jurisdiction	Perennial, intermittent, and ephemeral	Fibrous roots in streambed, rooted upland plants, benthic macroinvertebrates (presence and perennial indicator taxa), aquatic mollusks, fish, crayfish, amphibians, algae, wetland plants in streambed	Continuity of channel bed and bank, sinuosity, in-channel structure, streambed particle size, active/relict floodplain, depositional bars/benches, recent alluvial deposits, headcuts, grade control (natural), natural valley, 2nd or > order channel	Baseflow presence, iron oxidizing bacteria, leaf litter, organic debris drift accumulation, sediment on plants/debris, soil-based evidence of high- water table
Fritz et al. (2006)	Temperate USA (IN, KY, OH, IL, NH, NY, VT, WV, and WA)	No	Perennial, intermittent, and ephemeral	Benthic macroinvertebrates, amphibians, algal cover, algal assemblage, bryophyte assemblage, riparian canopy cover	Sinuosity, slope, depth, wetted width, depth to bedrock/groundwater table, streambed sediment moisture/size distribution	Water chemistry, habitat unit designation, water velocity, continuous hydrologic monitoring
Svec et al. (2005)	Eastern Kentucky	No	Perennial, intermittent, and ephemeral		Bankfull width, width to depth ratio, entrenchment ratio, slope, watershed area	
Ohio EPA (2012)	Ohio	Yes, as an assessment methodology for conducting use attainability analyses of primary headwater habitat streams	Perennial (cold water), intermittent/ perennial (warm water), ephemeral	Fish, benthic macroinvertebrates, amphibians (salamander community), riparian zone and floodplain quality	Average bankfull width, sinuosity, stream gradient, max pool depth, number of substrate types (includes leaf litter) and percentages of most predominant types	Water in channel/flow
Fairfax County Public Works and Environmental Services (2003)*	Fairfax County, VA	Yes, to comply with VA Chesapeake Bay Preservation Act (state law enforced by local governments); does not appear to be used by Corps Districts to support WOUS jurisdiction	Perennial and intermittent	Rooted aquatic plants in streambed, benthic macroinvertebrates, EPT taxa, bivalves, fish, amphibians, periphyton/green algae, wetland plants in streambed	Continuous bed and bank, sinuosity, riffle-pool sequence, substrate sorting, active/relict floodplain, bankfull bench present, recent alluvial deposits, braided channel, natural levees, 2nd or > order channel	Presence or absence of flowing water (>48 hrs since last rainfall), leaf litter, organic debris drift lines, sediment on plants/debris, redoximorphic soil features present in sides of channel or headcut, soil chroma

Source	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
James City County, Chesapeake Bay Board (2009)*	James City County, VA and tested for use in York, Gloucester and New Kent Counties, and the cities of Williamsburg and Newport News, VA	Yes, to comply with VA Chesapeake Bay Preservation Act (state law enforced by local governments); does not appear to be used by Corps Districts to support WOUS jurisdiction	Perennial and intermittent	Macrobenthos, gilled amphibians, fish	Continuity of channel bed and bank, sinuosity, in-channel structure, soil texture/depth of channel downcutting, degree of valley development, floodplain/in-channel bench, recent alluvial deposits	Groundwater discharge, leaf litter, flowing water in channel, Yorktown formation
DeBerry and Crayosky (2018)	Virginia	No; in review	Perennial	Macroinvertebrates, vertebrates (includes fish and amphibians)	Channel geometry, instream vegetation (indicates presence of stable depositional features)	Streamflow, streambed soils, off-site resources (e.g., interviews with residents or local professionals, county soil surveys, aerials)
Tennessee Department of Environment and Conservation (2011)*	Tennessee	Yes, to comply with TN Water Quality Control Act, as well as 401 ('waters of the state') and related state-level Aquatic Resource Alteration Permit program; does not appear to be used by Corps Districts to support WOUS jurisdiction	Perennial, intermittent, wet-weather conveyance (= ephemeral)	Fibrous roots in channel, rooted upland plants in channel, macroinvertebrates, bivalves/mussels, fish, crayfish in stream, amphibians, filamentous algae and periphyton, wetland plants in channel	Continuous bed and bank, sinuous channel, in-channel structure, sorting of soil textures, active/relict floodplain, depositional bars/benches, braided channel, recent alluvial deposits, natural levees, headcuts, grade control (natural), natural valley, 2nd or > order channel	Sub-surface flow/discharge into channel, water in channel and >48 hrs since significant rain, leaf litter in channel (January-September), organic debris drift accumulation, sediment on plants/debris, hydric soils in streambed or sides of channel, iron-oxidizing bacteria/fungus
Hansen (2001)	Western GA, NC, and SC (Chattooga River watershed)	No	Perennial, intermittent, and ephemeral	Aquatic insects	Channel definition, material movement, channel materials (includes amount of organic build-up)	Estimated flow duration, bed water level
Bent and Steeves (2006)	Massachusetts (excluding SE coast)	No	Perennial and intermittent			Not field based — variables in equation are: drainage area, areal % of sand and gravel deposits, areal % of forest land, and region (east or west)

Source	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
Olson and Brouillette (2006)	Vermont	Used as evidence in jurisdictional determinations conducted under Vermont Statute that a stream is perennial or intermittent; does not appear to be used by Corps Districts to support WOUS jurisdiction	Perennial and intermittent			Not field based – variables in equation are: drainage area, site elevation, ratio of basin relief to basin perimeter, and areal % of well and moderately well-drained soils in the basin

* Derived from the North Carolina DWQ method (may be from an earlier version than that cited in this document)

Table 3. Methods for assessing flow duration and their associated indicators in other regions of the U.S. and in other countries.

Source	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
Mazor et al. (2021a)	Arid West (parts of AZ, CA, CO, NM, NV, TX, UT, and WY)	Currently in beta testing; intended to be used by the Corps and EPA to support evidence of WOTUS jurisdiction once final	Perennial, intermittent, at least intermittent, and ephemeral	Wetland (hydrophytic) plants, aquatic macroinvertebrates (# and EPT), algae (presence and % cover), fish Supplemental info (for 'needs more information'): amphibians/snakes, perennial indicator macroinvertebrate taxa, iron-oxidizing fungi/bacteria		
Mazor et al. (2021b)	Western Mountains (parts of AZ, CA, CO, MT, NM, SD, UT, and WY)	Currently in beta testing; intended to be used by the Corps and EPA to support evidence of WOTUS jurisdiction once final	Perennial, intermittent, at least intermittent, and ephemeral	Aquatic macroinvertebrates (abundance and richness, includes perennial indicator taxa), algal cover, fish abundance and presence, differences in vegetation Supplemental info (not used in model): presence of aquatic or semi-aquatic amphibians and reptiles, iron-oxidizing fungi/bacteria	Bankfull width, sinuosity	Long-term precipitation, long-term maximum air temperature, snow influence (stratifies what indicators are used in the model and how they are interpreted)

Source	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
Nadeau (2015a)	Pacific Northwest (ID, OR, WA)	Yes; used by Corps Districts as supporting evidence of WOUS jurisdiction	Perennial, intermittent, and ephemeral	Benthic macroinvertebrate, wetland plants, riparian corridor, fish, amphibians/snakes	Slope, evidence of erosion/deposition, floodplain connectivity	
Topping et al. (2009)	Oregon Interim SDAM	No; superseded by the OR Final SDAM (Nadeau 2011) and Pacific Northwest method (Nadeau 2015). Was mostly used to test indicators being considered in a final SDAM	Perennial, intermittent, and ephemeral	Wetland plants, fibrous roots and rooted plants, streamer mosses or algal mats, iron-oxidizing bacteria, fungi, flocculent material, benthic macroinvertebrates, amphibians/snakes, fish, lichen line, riparian vegetation corridor	Continuous bed and bank, in-channel structure, soil texture or stream substrate sorting, erosional features, depositional features, sinuosity, headcuts and grade controls	Groundwater/hyporheic saturation, springs and seeps, debris piles/wrack lines, evenly disbursed leaf litter/loose debris, redoximorphic features in toe of bank
Surface Water Quality Bureau, NM Environment Department (2011)	New Mexico	Yes, as an assessment methodology for conducting use attainability analyses and to properly classify streams to satisfy NM water quality standards; does not appear to be used by Corps Districts to support WOUS jurisdiction	Perennial, intermittent, and ephemeral	**Level 1**: Fish and benthic macroinvertebrates (qualitative), filamentous algae and periphyton, riparian vegetation, rooted upland plants in streambed, iron oxidizing bacteria/fungi. **Level 2**: fish and benthic macroinvertebrates (quantitative), EPT taxa, bivalves, amphibians	**Level 1**: Sinuosity, floodplain and channel dimensions, channel structure, particle size or stream substrate sorting	**Level 1**: Water in channel, hydric soils, sediment on plants or debris, seeps/springs. **Level 2**: water in channel (logged data), hyporheic zone/groundwater table
Gallart et al. (2017)	Mediterranean Europe	No	Intermittent-pools, intermittent-dry, episodic-ephemeral, perennial; Hyperrheic, eurheic, oligorheic, arheic, hyporheic/dry			Hydrologic metrics (based on modeled or recorded flow), citizen observations
Straka et al. (2019)	Czech Republic	No	Intermittent, near-perennial, and perennial	Benthic macroinvertebrates		

Source	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
McCleary et al. (2012)	Alberta, Canada ('Foothills' region)	No, guides forest management	Upland, swale, discontinuous channel, seepage-fed channel, fluvial channel	In-channel vegetation presence; plant community type (to determine soil moisture regime)	Continuous channel, presence of headcuts, pools, and 'organic bridges', bankfull width, undercut width, particle size/substrate sorting, riffle-pool sequence	Water in channel
Savage and Rabe (1979)	Idaho	No	Ephemeral, "spring streams" and permanent	Rooted vascular plants in channel, bryophytes, aquatic invertebrates, amphibians, fish	Gradient, substrate	Water in channel

Table 4. Summary of indicators included in flow-duration field assessment methods that are described in Tables 2 and 3. Highlighted columns are those SDAMs developed for use in the NE/SE region.

Indicator	North Carolina	Temperate USA	Kentucky	Ohio	Fairfax County, VA	James City County, VA	Virginia	Tennessee	Western GA, NC, SC	Arid West (beta)	Western Mountains (beta)	Pacific Northwest	Oregon Interim Method	New Mexico (Phase 1)	New Mexico (Phase 2)	Mediterranean	Czech Republic	Alberta (Foothills)	Idaho
Geomorphology																			
Bankfull width and/or depth		X	X	X							X							X	
Continuous bed and banks presence/consistent in-channel geometry	X				X	X	X	X	X				X					X	
Undercut width																		X	
Depositional or erosional features in the channel (e.g., bankfull benches or depositional bars)	X				X	X	X	X					X						
Depositional or erosional features on the floodplain (e.g., recent alluvial deposits, natural levees)	X				X	X		X											
Distinct substrate composition in streambed from adjacent uplands (particle size or substrate sorting/movement)	X	X			X	X		X	X				X	X				X	X
Entrenchment ratio (floodplain/channel dimension)		X	X											X					
Evidence of active or relict floodplain	X				X			X											
Presence of natural valley/degree of development	X					X		X											
Presence of headcuts	X	X						X					X					X	

Indicator	North Carolina	Temperate USA	Kentucky	Ohio	Fairfax County, VA	James City County, VA	Virginia	Tennessee	Western GA, NC, SC	Arid West (beta)	Western Mountains (beta)	Pacific Northwest	Oregon Interim Method	New Mexico (Phase 1)	New Mexico (Phase 2)	Mediterranean	Czech Republic	Alberta (Foothills)	Idaho
In-channel structure/sequences of erosional and depositional features (e.g., riffle-pool, step-pool)	X	X			X	X		X					X	X				X	X
Presence of a braided channel					X			X											
Presence of natural grade control	X							X											
Stream order	X							X											X
Sinuosity	X	X		X	X	X		X			X		X	X					
Slope/Gradient		X	X	X								X						X	X
Organic bridge																		X	
Hydrology																			
Continuous logged data		X													X				
Groundwater observation	X	X		X		X		X					X	X					
Distribution/presence of leaf litter/packs or other organic debris	X	X		X	X	X		X	X				X						
Soil-based evidence of high-water table—can include hydric soils/soil chroma, redoximorphic features, or organic streaking	X				X		X	X					X	X					
Modeled hydrology																X			
Observed aquatic state (e.g., presence or level of water in channel)		X			X	X		X	X					X	X	X			
Reported aquatic state from interviews or off-site resources							X									X			
Observed or reported soil saturation		X		X									X	X		X			
Observation of baseflow	X			X												X		X	X
Presence of wrack or drift lines	X				X			X					X						
Sediment deposition on plants or debris	X				X			X						X					
Presence of seeps and springs													X	X					X
Iron-oxidizing bacteria or fungi[1]	X							X		X			X	X					
Velocity		X																	
Presence of geological formation that contributes to baseflow (Yorktown formation)						X													

Indicator	North Carolina	Temperate USA	Kentucky	Ohio	Fairfax County, VA	James City County, VA	Virginia	Tennessee	Western GA, NC, SC	Arid West (beta)	Western Mountains (beta)	Pacific Northwest	Oregon Interim Method	New Mexico (Phase 1)	New Mexico (Phase 2)	Mediterranean	Czech Republic	Alberta (Foothills)	Idaho
Biology																			
Algae (includes alive or dead algal mats)/periphyton	X	X			X			X		X	X		X	X					X
Lichens													X[5]						X
Bryophytes (includes streamer mosses)		X											X						X
Fibrous roots in channel	X							X											
Wetland or aquatic vegetation in channel	X				X			X		X		X	X					X	X
Upland vegetation in channel	X							X					X	X				X	
Distinct riparian corridor/differences in vegetation											X	X	X[5]	X					
Aquatic macroinvertebrates[2] – Presence/Ease of Detection and/or Abundance and/or Diversity[3]	X	X		X	X	X			X	X	X	X	X	X	X				
Aquatic macroinvertebrates[4] - Indicator taxa (e.g., EPT taxa)	X			X	X		X	X		X	X	X	X		X		X		X
Aquatic macroinvertebrates – Traits																	X		
Crayfish – Presence and/or Abundance[3]	X							X											
Amphibians – Presence and/or Abundance and/or Diversity[3]	X	X		X	X	X	X	X				X	X		X				X
Amphibians – Indicator Taxa		X		X							X	X							
Reptiles – Presence or Indicator Taxa										X		X	X						
Aquatic Mollusks/Bivalves – Presence/Ease of Detection and/or Abundance[3]	X				X			X							X				
Fish – Presence/Ease of Detection and/or Abundance and/or Diversity (of life stages, generally)[3]	X			X	X	X	X	X		X	X	X	X	X	X				
Fish –Indicator taxa				X															X
Climate[6]																			
Long-term precipitation											X								
Long-term maximum annual air temperature											X								
Snow influence (used for stratification)											X								

[1] This indicator is included in the biological category in the Oregon Interim and Tennessee methods but is considered a hydrology indicator in the North Carolina method (non-categorized supplemental indicator in NM method). The presence of iron-oxidizing bacteria or fungi generally reflects the presence of groundwater inputs, so it has been included in the hydrology category for this literature review.

[2] Other aquatic invertebrate taxa are evaluated separately in the NC and TN methods (crayfish and mollusks/bivalves) and the Fairfax County method (bivalves)

[3] Indicator scoring or evaluation is often a composite of presence/absence, abundance, and/or diversity depending on the method; therefore, these metrics were combined for this table.
[4] Includes aquatic insects and worms as well as aquatic mollusks (snails and mussels)
[5] Only used in arid and/or alpine areas for this method
[6] Not tested as field indicators but included in analysis as one of a battery of potential climactic indicators

Table 5. Evaluation criteria for indicators identified in the literature review.

Indicator	Consistency	Repeatability	Defensibility	Rapidness	Objectivity	**Priority Indicator**	Robustness	Practicality	**Proposed**
Geomorphology									
Bankfull width and/or depth	X	X		X	X	No	X	X	**Yes[2]**
Continuous bed and banks presence/consistent in-channel geometry	X	X		X		No	X	X	**Yes[1]**
Undercut width		X		X	X	No	X	X	**No**
Depositional or erosional features in the channel (e.g., bankfull benches or depositional bars)	X	X		X		No		X	**Yes[1]**
Depositional or erosional features on the floodplain (e.g. recent alluvial deposits, natural levees)	X	X		X		No		X	**Yes[1]**
Distinct substrate composition in streambed from adjacent uplands (particle size or substrate sorting/movement)	X	X		X		No	X	X	**Yes[1]**
Entrenchment ratio (floodplain/channel dimension)	X	X		X	X	No		X	**Yes[2]**
Evidence of active or relict floodplain		X		X		No	X	X	**Yes[1]**
Presence of natural valley/degree of development	X	X		X		No		X	**Yes[1]**
Presence of headcuts	X	X		X	X	No	X	X	**Yes[1]**
In-channel structure/sequences of erosional and depositional features (e.g., riffle-pool, step-pool)	X	X		X		No	X	X	**Yes[1]**
Presence of a braided channel	X			X		No		X	**No**
Presence of natural grade control	X	X		X		No		X	**Yes[1]**
Stream order	X	X		X	X	No		X	**Yes[1]**
Sinuosity	X	X		X	X	No	X	X	**Yes[1]**
Slope/Gradient	X	X	X	X	X	Yes	X	X	**Yes**
Organic bridge		X		X		No		X	**No**
Hydrology									
Continuous logged data	X	X	X		X	No	X		**No**
Groundwater observation	X	X	X		X	No	X		**No**
Distribution/presence of leaf litter/packs or other organic debris	X	X		X		No		X	**Yes[1]**
Soil-based evidence of high-water table—can include hydric soils/soil chroma, redoximorphic features, or organic streaking	X	X	X	X	X	Yes	X	X	**Yes**
Modeled hydrology	X	X	X		X	No	X		**No**
Observed aquatic state (e.g. presence or level of water in channel)	X	X	X	X	X	Yes		X	**Yes**
Reported aquatic state from interviews or off-site resources		X	X		X	No	X		**No**
Observed or reported soil saturation		X	X	X	X	No		X	**No**
Observation of baseflow	X	X	X	X		No	X		**Yes[1]**
Presence of wrack or drift lines	X	X		X		No		X	**Yes[1]**
Sediment deposition on plants or debris	X	X		X	X	Yes	X	X	**Yes[1]**
Presence of seeps and springs	X	X	X	X	X	Yes	X	X	**Yes**
Iron-oxidizing bacteria or fungi[1]	X	X	X	X	X	Yes	X	X	**Yes**
Velocity		X		X	X	No	X	X	**No**

Indicator	Consistency	Repeatability	Defensibility	Rapidness	Objectivity	**Priority Indicator**	Robustness	Practicality	**Proposed**
Presence of geological formation that contributes to baseflow (Yorktown formation)	X		X	X		No		X	No
Biology									
Algae (includes live or dead algal mats)/periphyton	X	X	X	X	X	Yes		X	**Yes**
Lichens		X	X	X	X	No		X	**No**
Bryophytes (includes streamer mosses)	X	X	X	X	X	Yes		X	**Yes**
Fibrous roots in channel	X	X		X		No		X	**Yes**[1]
Wetland or aquatic vegetation in channel	X	X	X	X	X	Yes		X	**Yes**
Upland vegetation in channel	X	X	X	X	X	Yes		X	**Yes**
Riparian vegetation	X	X	X	X	X	Yes		X	**Yes**
Aquatic macroinvertebrates – Presence/Ease of Detection and/or Abundance and/or Diversity	X	X	X	X	X	Yes	X	X	**Yes**
Aquatic macroinvertebrates - Indicator taxa (e.g. EPT taxa)	X	X	X	X	X	Yes		X	**Yes**
Aquatic macroinvertebrates – Traits	X	X			X	No	X	X	**No**
Crayfish – Presence and/or Abundance	X	X	X	X	X	Yes	X	X	**Yes**
Amphibians – Presence and/or Abundance and/or Diversity	X	X	X	X	X	Yes	X	X	**Yes**
Amphibians – Indicator Taxa	X	X	X	X	X	Yes		X	**Yes**
Reptiles – Presence	X	X	X	X	X	Yes		X	**Yes**
Aquatic Mollusks/Bivalves – Presence/Ease of Detection and/or Abundance	X	X	X	X	X	Yes	X	X	**Yes**
Fish – Presence/Ease of Detection and/or Abundance and/or Diversity (of life stages, generally)	X	X	X	X	X	Yes		X	**Yes**
Fish –Indicator taxa		X	X		X	No			**No**
Additional indicators from primary literature									
Geomorphology									
Max pool depth*		X		X	X	No	X	X	**Yes**[2]
Hydrology									
Dissolved O_2 *		X		X	X	No		X	**No**
Water column organic C+		X		X	X	No		X	**No**
Woody jams§		X	X	X	X	No	X	X	**No**
Biology									
Diatom abundance+		X			X	No			**No**
Bird abundance+		X			X	No			**No**
Terrestrial arthropods+		X	X	X	X	No			**No**
Canopy cover+	X	X		X	X	No		X	**No**
Riparian vegetation – diversity+	X	X	X		X	No			**No**
Microbial diversity+		X	X		X	No			**No**

[1]: Non-priority indicator proposed for inclusion because it is required by the North Carolina Method (NCDWQ 2010);
[2]: Non-priority indicator proposed for inclusion because studies identified in Section 4 suggest a potential relationship with flow duration.
* Identified in both AW and WM literature reviews
+ Identified in AW literature review
§ Identified in WM literature review

3.1 North Carolina

This method, developed by the North Carolina Division of Water Quality (2010), includes 9 biological, 11 geomorphic, and 6 hydrologic indicators to determine if a stream is perennial, intermittent, or ephemeral, as well as to designate locations in the landscape as origins of streamflow, or sinks where flow ceases. Indicators are scored to yield an index, with more indicators (or more robustly evident indicators) yielding a higher score. Scores for each indicator range from 0 to 3 or 0 to 1.5 depending on whether it is primary or secondary and are generally allocated using the descriptors in Figure 4, though some indicators have 'yes' or 'no' answers instead of a range. To be considered at least intermittent, a stream reach must score at least a 19 or above, with scores at 30 or above indicative of a perennial channel. Scores less than 19 indicate the channel is ephemeral. However, the presence of specific taxa (fish, crayfish, amphibians, or clams) or more than one benthic macroinvertebrate that requires water for their entire life cycle (later instars of certain aquatic insect and mollusca families) can also result in a perennial designation, even if scores are low.

Category	Description
Absent	The character is not observed
Weak	The character is present but you have to search intensely (i.e., ten or more minutes) to find and evaluate it
Moderate	The character is present and observable with brief (i.e., one or two minutes) searching and evaluation
Strong	The character is easily observable and quickly evaluated

Figure 4. NC SDAM general scoring guidance (from NC DWQ 2010).

This method applies within a state that is included in both the NE and SE regions and has been used as the basis for active SDAMs in both Virginia and Tennessee (see below). Fritz et al. (2013) evaluated the method's ability to correctly classify streams of differing flow permanence in forested catchments of the Piedmont and Southeastern Plains ecoregions of South Carolina, in both the wet and dry seasons. In addition to the NC method indicators, the authors also measured bankfull width and depth for each reach, and calculated drainage area, elevation, channel and valley slope, and relief ratio. The authors found the NC method tended to overestimate the flow permanence class of intermittent reaches, though the method itself was generally seasonally stable. Presence of baseflow was the most important predictor variable of streamflow duration in the classification model that used attribute scores from both the wet and dry seasons. When only dry season scores were used, other variables important for distinguishing between flow classes included presence of macrobenthos, presence of rooted upland plants in the streambed, and presence of fibrous roots in the streambed, in addition to the added variables of bankfull width, drainage area, and ecoregion.

Lampo (2014) tested the use of the NC method in agricultural watersheds in southern Illinois. The author found that the ability of the NC method to distinguish ephemeral from intermittent and perennial streams was successful 100% of the time, based on comparisons to direct measurement or observation of flow. However, when compared to the flow duration derived from direct measurements or observations of flow, the NC method incorrectly categorized intermittent and perennial streams 28% and 17% of the time, respectively. The author also found that watershed area and bankful depth and width had a significant positive correlation with flow duration as determined by the NC stream score, similar to Fritz et al. (2013).

3.2 Temperate US (IN, KY, OH, IL, NH, NY, VT, WV, and WA)

Fritz et al. (2006) described a comprehensive suite of protocols for measuring potential flow permanence indicators in headwater streams, which, due to their position in the landscape, are more prone to drying. The suite of indicators and description of collection methods described is more comprehensive than the other listed SDAMs, but no conclusive flow duration classification is drawn upon at the end of the analysis. Indicators are physical or biological and include channel slope, basic channel geomorphology (bankfull width and depth, entrenchment ratio), water depth (maximum pool depth, thalweg depth), macroinvertebrates, and algae, among others. Publications following this report (Fritz et al. 2008; Johnson et al. 2009; Fritz et al. 2009; Roy et al. 2009) assess the effectiveness of each indicator separately.

3.3 Eastern Kentucky

This method by Svec et al. (2005) was developed to determine the flow duration of a stream (ephemeral, intermittent, or perennial) in the context of determining required silivicultural best management practices in the eastern coalfield region of Kentucky. The authors measured a suite of channel geometry characteristics to determine their power to predict flow duration, including bankfull width, mean bankfull depth, width to depth ratio, flood prone width, streambed slope, depth to bedrock, entrenchment ratio, and cross-sectional area. The most predictive measurements of flow duration were found to be watershed area, stream slope, bankfull width, width to depth ratio, and entrenchment ratio. However, it is important to note that none of the streams sampled in this study were truly ephemeral (defined in this study as having measureable discharge <10% of the time), with no streams having <50% flow duration. Therefore, predictive models developed from data collection in this study may not apply as robustly to ephemeral or near-ephemeral intermittent streams as they do to perennial streams or near-perennial intermittent streams.

3.4 Ohio

Ohio EPA (2012) has developed an assessment and classification method for Primary Headwater Habitat (PHWH; generally, drainage areas less than 1.0 mi^2 and deep pools less than

40 cm) to better evaluate water quality in small headwater stream ecosystems. This method determines different stream classes (Class I, II, and III) based on the type of biological community the stream can support. These classes are partially based on flow duration, where Class I streams are considered ephemeral, Class II streams are considered intermittent to perennial (warmwater), and Class III streams are considered perennial streams influenced by groundwater (coldwater). There are three levels of assessment, where the first two levels are considered ‘rapid’: Level 1 is a physical assessment of habitat using the headwater habitat evaluation index (HHEI), Level 2 incorporates qualitative biological sampling, and Level 3 is a quantitative biological assessment of vertebrate and macroinvertebrate communities (taxa evaluated to lowest practicable taxonomic level). Level I metrics include substrate (including habitat such as leaf packs and fine detritus), maximum pool depth, and average bankfull width. Scores from these metrics determine the HHEI, which is then fed into the flowchart in Figure 5. Generally, Level I, combined with Level II, is enough to determine the PHWH stream class; however, the use of Level III is the final arbiter of stream class.

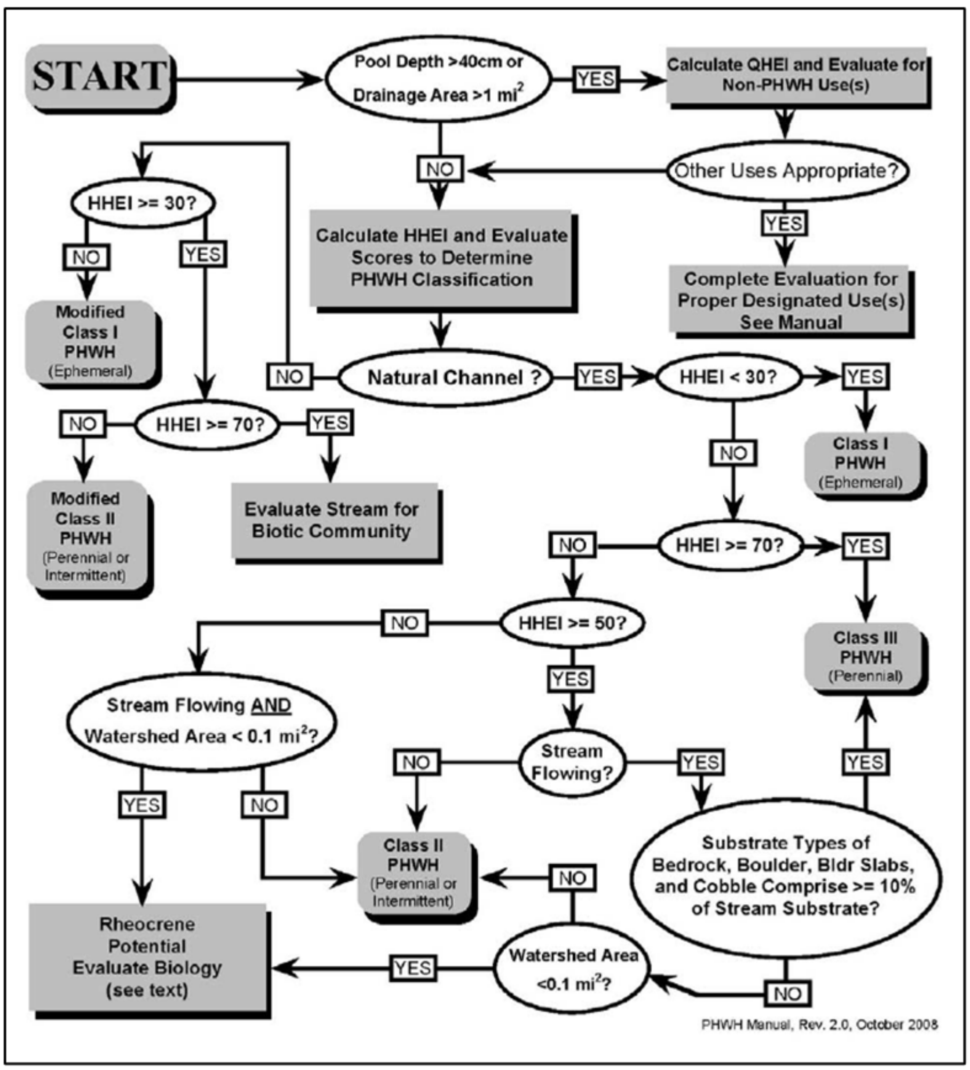


Figure 5. PHWH stream classification flow chart based on HHEI scoring (from Ohio EPA 2012).

3.5 Fairfax County and James City County, Virginia

These VA counties have developed separate methods to determine whether a stream is perennial to facilitate compliance with the VA Chesapeake Bay Preservation Act; however, both are largely derived from earlier versions of the NC SDAM and are scored in the same way (see Figure 4), though the types and total number of indicators and the perennial/intermittent thresholds are different from NC and from each other. In addition, the Fairfax County method (2003) also used an unpublished manuscript of the 'Qualitative Field Procedures for Perennial Stream Determinations', later published by DeBerry and Crayosky (2018; see below), to develop its protocol. Fairfax County's method has 26 total indicators, including 10 for geomorphology, 7 for streamflow, hydrology, and streambed soils, and 9 for biology. The minimum threshold for a perennial rating is 25; however, streams with lower scores can be classified perennial if additional information supports this classification (e.g., presence of EPT or other taxa with an extended aquatic life stage, long-term observations by a resident or local professional).

James City County's method (2009) has 14 total indicators, including 7 for geomorphology, 4 for hydrology, and 3 for biology. Generally, streams scoring 18 points or more are classified as perennial and streams scoring 10 points or less are classified as intermittent. For those streams scoring between 10 and 18, the perennial flow threshold is 14 points with a range of +/- 2. This range allows for classifications not strictly based on the threshold value, as long as the preponderance of the evidence and professional judgement support the flow determination (e.g. an intermittent stream can have a score up to 16 and a perennial stream can have a score as low as 12). Additional factors specified to support a determination include soil mottling, periphyton, grade control, and offsite stormflow inputs, but not specific biological indicator taxa. This method has been tested in surrounding counties (Gloucester, New Kent, and York) and cities (Williamsburg and Newport News) in the upper coastal plain of VA and found to be an accurate tool for identifying perennial water bodies in these areas as well (VA DCR 2010).

3.6 Virginia (state-wide)

DeBerry and Crayosky (2018) identified a set of 7 qualitative indicators (6 field, 1 off-site) that could be used to determine if a stream has a perennial flow duration in Virginia. Unlike the two other SDAMs developed in the state, this method is not based on a point system or a numerical index, but instead builds on positive corroborative evidence that a stream is perennial. Therefore, if a majority of the indicators (4 or more) are present (e.g., dry season flow) or suggest perennial streamflow (e.g., presence of macroinvertebrates having an aquatic life cycle greater than a year) than the stream is considered perennial. This method is not currently being used in an official capacity but is under review by regulatory agencies in VA for use as an approved perennial stream determination approach.

3.7 Tennessee

This method is also derived from the NC method, though it differs in that the primary goal is not necessarily to determine flow duration, but to determine if a channel is a jurisdictional stream (intermittent or perennial) or a 'wet-weather conveyance' that is not subject to regulatory jurisdiction as a water of the state (WWC; generally ephemeral). To that end, there is a set of 9 'yes' or 'no' questions that, if at least one is answered in the affirmative, determine whether the channel is a stream or a WWC (Figure 6). If no primary indicator is present, an evaluator completes the secondary indicator score sheet, which is largely a replica of the North Carolina method (2010 version, with slight modifications), to determine if the channel is subject to regulatory jurisdiction. If a channel scores less than a 19 (intermittent threshold), it is considered a WWC; anything above is considered a stream.

Primary Indicators	NO	YES
1. Hydrologic feature exists solely due to a process discharge		WWC
2. Defined bed and bank absent, dominated by upland vegetation / grass		WWC
3. Watercourse dry anytime during February through April 15th, under normal precipitation / groundwater conditions		WWC
4. Daily flow and precipitation records showing feature only flows in direct response to rainfall		WWC
5. Presence of multiple populations of obligate lotic organisms with ≥ 2 month aquatic phase		Stream
6. Presence of fish (except *Gambusia*)		Stream
7. Presence of naturally occurring ground water table connection		Stream
8. Flowing water in channel and 7 days since last precipitation in local watershed		Stream
9. Evidence watercourse has been used as a supply of drinking water		Stream

Figure 6. Primary indicators to determine if a channel is a stream or a WWC (from TDEQ 2011).

3.8 Chattooga River Watershed (western GA, NC, and SC)

Using stream networks identified and digitized for the Chattooga River watershed in mountainous western GA, NC, and SC, Hansen (2001) presents a set of physical and biological indicators that can be used to distinguish between perennial, intermittent, and ephemeral streams (Figure 7). It is important to note that these criteria are based on the author's stream observations over many years and have not been formally tested or verified for their reliability. This work was completed primarily to better estimate flow type extent throughout the Chattooga River watershed and relationships to stream order.

Criteria	Stream type		
	Perennial	Intermittent	Ephemeral[a]
Channel	Defined	Defined	Not defined
Flow duration (estimated)	Almost always	Extended, but interrupted	Stormflow only
Bed water level	Above channel	Near channel surface	Below channel
Aquatic insects	Present	Few, if any	None
Material movement	Present	Present, less obvious	Lacking or limited
Channel materials	Scoured, flow sorted	Scoured or flow sorted	Mostly soil materials
	No organic buildup	Lacks organic buildup	Organic buildup

[a] Healed gully channels were classed as ephemerals when there were no recent signs of flow or scour. When forested, there is evidence of organic accumulations and decomposition.

Figure 7. Physical and biological criteria used to delineate flow types in Hansen (2001).

3.9 Massachusetts and Vermont

In Massachusetts and Vermont, logistic regression equations were developed to determine the probability of a stream reach being perennial or intermittent. These are not field based methods but could be complimentary to field surveys if developed for other states or regions, and at least in Vermont's case, are already being used as supporting evidence for jurisdictional determinations. The Massachusetts regression model (Bent and Steeves 2006) is applicable for stream sites with drainage areas between 0.04 and 2.0 sq. miles (above 2.0 sq. miles, the streams became reliably perennial), excluding the southeastern coastal region of the state. Factors in the equation include drainage area, areal percent of sand and gravel deposits (influenced by glaciation), areal percentage of forest land, and whether the stream was in the eastern or western portion of MA. A logistic regression equation using these variables was found to be about 75% accurate; in other words, there is about a 75% chance that a stream site is correctly classified as perennial using the equation. The authors developed an automated procedure to map stream types using the equation and did so in the Shawsheen River basin in northeast MA as a case study. It is unknown whether other basins have been mapped since the equation was developed. The procedure requires a National Hydrography Dataset (NHD) of at least a 1:24,000 scale, elevation derived datasets (flow direction, flow accumulation and catchment grids) and data layers of equation variables.

The state of Vermont has developed its own hydrography dataset (VHD) at a 1:5,000 scale, which is much finer than what is available nationally (finest scale NHD is generally 1:24,000). Olson and Brouillette (2006) developed a logistic regression equation to determine the probability a stream was intermittent in Vermont and used it to assign streamflow characteristics to channels shown on the VHD. Factors in the equation include drainage area, elevation of the site, ratio of basin relief to basin perimeter, and areal percentage of well and moderately well-drained soils. A logistic regression equation using these variables was found to be about 85% accurate; in other words, there is about an 85% chance that a stream site is correctly classified as intermittent using the equation. The VHD dataset with regression derived streamflow classifications is cited by the Vermont Department of Environmental Conservation (VDEC) as an evaluative parameter when conducting jurisdictional determinations under the Vermont Stream Alteration Permit Program (VDEC 2018).

3.10 Arid West (Beta)

This method is the first produced as part of the cooperative regional SDAM expansion effort described in Section 1, developed using the process outlined in Fritz et al. (2020). Based on the statistical analysis of field sampled data, five biological field indicators were found to support an accurate determination of a stream's flow duration class in the Arid West:

1) How many hydrophytic plant species are growing in the channel, or within one half-channel width of the channel?
2) How many aquatic macroinvertebrate individuals are found?
3) Is there evidence of aquatic stages of EPT taxa?

4) Are algae found on the streambed?
5) Are single indicators (i.e., the presence of fish or ≥10% algal cover) of intermittent or perennial streamflow duration observed?

The first four indicators are evaluated together to assign a preliminary flow duration class; the presence of single indicators, #5 above, determines that a reach is “at least intermittent”, even if the assigned preliminary flow class determined from indicators 1-4 was ephemeral. Field-measured indicator data is applied to the decision matrix shown in Figure 8, sequentially from left to right, to determine flow class (Mazor et al. 2021a).

1. Hydrophytic plant species	2. Aquatic invertebrates	3. EPT taxa	4. Algae	5. Single indicators • fish present • algae cover $\geq$ 10%	Classification
None	None	Absent	Absent	Absent	**Ephemeral**
				Present	**At least intermittent**
			Present	Absent	**Need more information**
				Present	**At least intermittent**
	Few (1-19)	Absent	Absent	Absent	**Need more information**
				Present	**At least intermittent**
			Present	Absent	**Need more information**
				Present	**At least intermittent**
		Present			**At least intermittent**
	Many (20+)	Absent	Absent	Absent	**Need more information**
				Present	**At least intermittent**
			Present	Absent	**Need more information**
				Present	**At least intermittent**
		Present			**At least intermittent**
Few (1-2)	None	Absent	Absent	Absent	**Need more information**
				Present	**At least intermittent**
			Present		**At least intermittent**
	Few (1-19)	Absent	Absent		**Intermittent**
			Present		**At least intermittent**
		Present			**At least intermittent**
	Many (20+)	Absent	Absent		**Intermittent**
			Present		**At least intermittent**
		Present	Absent		**At least intermittent**
			Present		**Intermittent**
Many (3+)	None	Absent	Absent	Absent	**Need more information**
				Present	**At least intermittent**
			Present		**At least intermittent**
	Few (1-19)	Absent			**At least intermittent**
		Present			**Perennial**
	Many (20+)	Absent			**At least intermittent**
		Present			**Perennial**

Figure 8: Streamflow classifications based on field-measured indicator data in the beta SDAM for the Arid West (Mazor et al. 2021a)

3.11 Western Mountains (Beta)

This method is the second produced as part of the cooperative regional SDAM expansion effort described in Section 1, developed using the process outlined in Fritz et al. (2020). Based on the statistical analysis s of field sampled data, six field indicators (4 biological and 2 geomorphological) and two climactic indicators available through online geodatabases were found to support a determination of a stream's flow duration in the Western Mountains (Mazor et al. 2021b):

Field Indicators

1) The abundance and richness of aquatic invertebrates (specifically, the total abundance, the abundance of mayflies, and the abundance and richness of perennial indicator families)
2) Algal cover on the streambed (%)
3) Fish abundance (0-3 score, where 0 is no fish or only mosquitofish observed)
4) Differences in vegetation between the channel and surrounding uplands (0-3 score, where 0 is no difference)
5) Bankfull channel width
6) Sinuosity (0-3 score, where 0 is poor)

Climactic Indicators (supported through a web application designed for this effort)

7. Long-term precipitation (average precipitation in May and October)
8. Long-term maximum annual air temperature

The presence of fish may also be used as a single indicator to classify a stream as "at least intermittent" even if other indicators suggest an ephemeral classification. This method is stratified by snow-influence, as shown in Figure 9.

Snow-influenced areas	**Non-snow influenced areas**
Aquatic invertebrates: • Total abundance • Abundance of perennial indicator families • Number of perennial indicator families	Aquatic invertebrates: • Abundance of mayflies • Number of perennial indicator families
Algal cover on the streambed	Algal cover on the streambed
Fish presence (as a single indicator)	Fish abundance (as a core indicator) and Fish presence (as a single indicator)
	Differences in vegetation
Bankfull channel width	Bankfull channel width
	Sinuosity
Climate • October precipitation	Climate • May precipitation • Annual maximum temperature

Figure 9: Field-measured and desktop indicator data used in the beta SDAM for the Western Mountains based on snow-influence (Mazor et al. 2021b).

The beta SDAM for the Western Mountains relies on a random forest model to make stream flow duration classifications (ephemeral, intermittent, at least intermittent, and perennial) and a web application is publicly available to complete the assessment. Supplemental indicators that provide further evidence for a streamflow classification are also noted in the field (but are not used as input into the random forest model): presence of aquatic or semi-aquatic life stages of reptiles and amphibians, and the presence of iron-oxidizing fungi and bacteria.

3.12 Pacific Northwest

For purposes of classifying perennial, intermittent and ephemeral streams in the Pacific Northwest, Nadeau (2015) developed a method that uses five biological and physical habitat indicators: 1) presence of aquatic macroinvertebrates; 2) number of mayflies (order Ephemeroptera); 3) presence of perennial indicator taxa from Mazzacano and Black (2008) or Blackburn and Mazzacano (2012); 4) presence of wetland indicator plants (specifically, SAV, FACW, or OBL) as determined from regionally appropriate wetland plant lists; and 5) valley slope. Additional indicators, such as the presence of fish, aquatic stages of amphibians, and evidence of sediment erosion or deposition, are also considered as contextual support for the flow duration determination. Indicators are measured in an objective fashion, without requiring subjective or qualitative visual assessments by practitioners. This data-driven method resulted from a three-state study (Nadeau et al. 2015) of the Oregon Interim Method (Topping et al. 2009; see 3.2.11).

Indicators are evaluated with a simple branching flow-chart (Figure 10), and not all indicators are needed to make a determination at every site. Consequently, it is among the simplest tools to implement. This method strongly emphasizes biological indicators, including only one geomorphological indicator (i.e., slope), and no hydrological indicators.

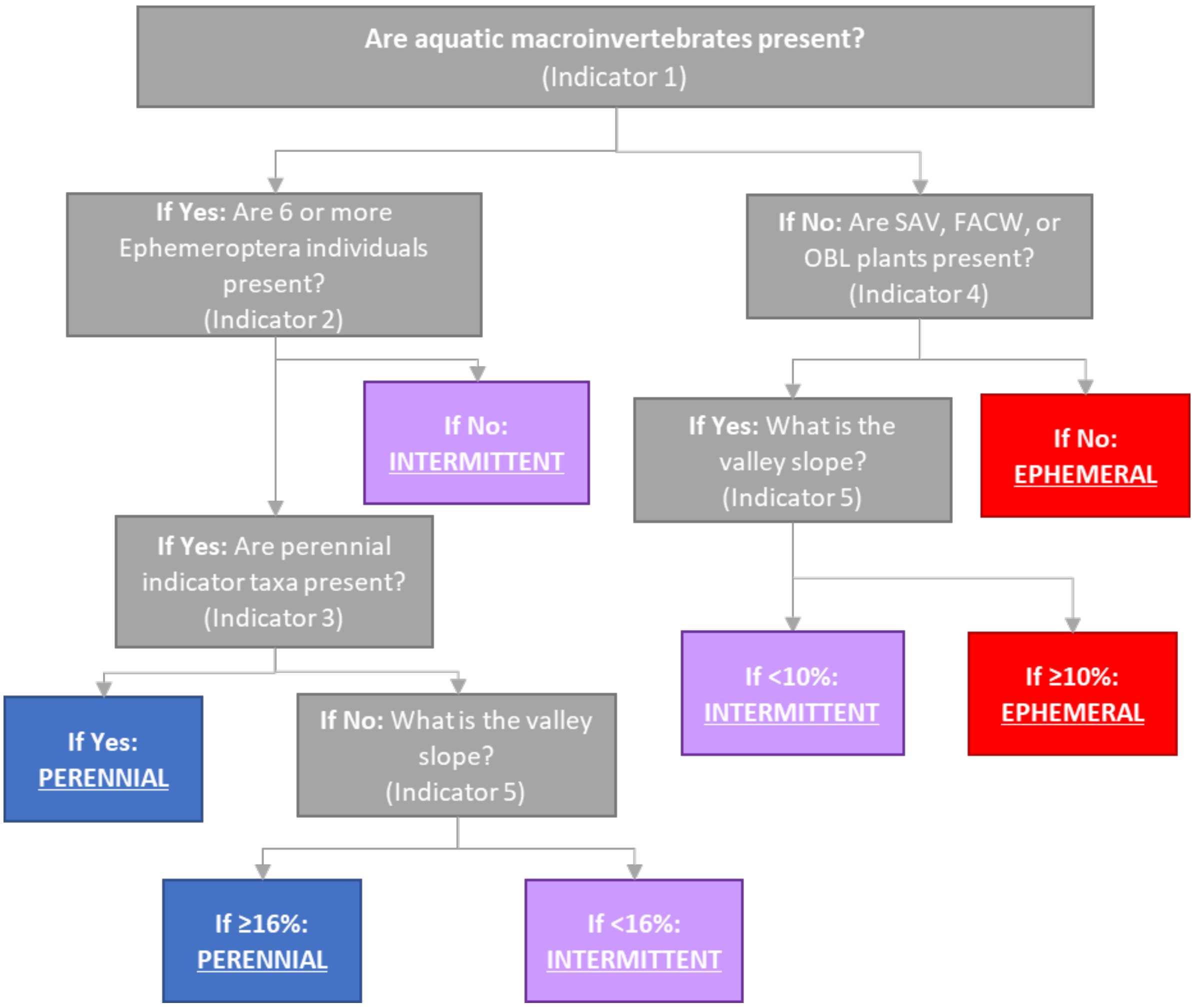


Figure 10. Flowchart used to determine flow class in the Pacific Northwest method (adapted from Nadeau 2015).

3.13 Interim Oregon Method

Prior to the development of the method of Nadeau (2015) for the Pacific Northwest, Topping et al. (2009) developed a flow duration assessment tool for Oregon very similar to the NC method that evaluates a series of geomorphological, hydrological, and biological indicators as absent, weak, moderate, or strong. In general, the strength of the indicator is considered evidence of longer flow durations. Each indicator is scored and summed; if the total score is below 13, the stream is considered ephemeral, and if the total score is above 25, the stream is considered perennial. Single indicators (e.g., presence of fish, amphibians, or aquatic macroinvertebrates) may result in a classification of "at least intermittent.". In contrast to Nadeau (2011, 2015), assessing the strength of the indicators requires subjective visual assessments by users.

Note that the release of the data-driven Final Streamflow Duration Assessment Method for Oregon (Nadeau 2011) superseded the use of the Interim Method in Oregon; the Final Oregon Method was, in turn, superseded by the substantively similar Streamflow Duration Assessment

Method for the Pacific Northwest (Nadeau 2015) as a result of a three-state validation study (Nadeau et al. 2015).

3.14 New Mexico

The New Mexico Environment Department (NMED) developed a two-phase method for assessing flow duration (NMED 2011) for streams throughout the state. The first phase is more rapid and is sometimes sufficient to classify a stream as perennial, intermittent, or ephemeral. This first phase is very similar to the NC method and relies on qualitative sampling of benthic macroinvertebrates, fish, filamentous algae, and other organisms, plus field observation of channel morphology and soils. In some cases, a second phase consisting of quantitative fish and benthic macroinvertebrate samples may be necessary. This second phase also requires the use of continuous loggers or stream gauges to measure water presence. In this method, 14 indicators of flow duration ("attributes") are scored, yielding a quantitative index that forms the basis of the classification (Table 6). Notably, this method may result in ambiguous situations (gray rows in Table 6), which may be resolved by more intensive "level 2" analysis, and by investigation of adjacent reaches. Certain indicators (specifically, fish and aquatic macroinvertebrates) may result in a perennial designation, even if scores are low.

Table 6. Score interpretation for the New Mexico method.

Waterbody type	Level 1 total score	Determination
Ephemeral	Less than 9.0	Stream is ephemeral
	≥ 9.0 and < 12.0	Stream is recognized as intermittent until further analysis indicates that the stream is ephemeral.
Intermittent	≥ 12 and ≤ 19.0 ***or*** score is lower but aquatic macroinvertebrates and/or fish are present	Stream is intermittent
	> 19.0 and ≤ 22.0	Stream is recognized as perennial until further analysis indicates that the stream is intermittent
Perennial	Greater than 22.0	Stream is perennial

3.15 Mediterranean Europe

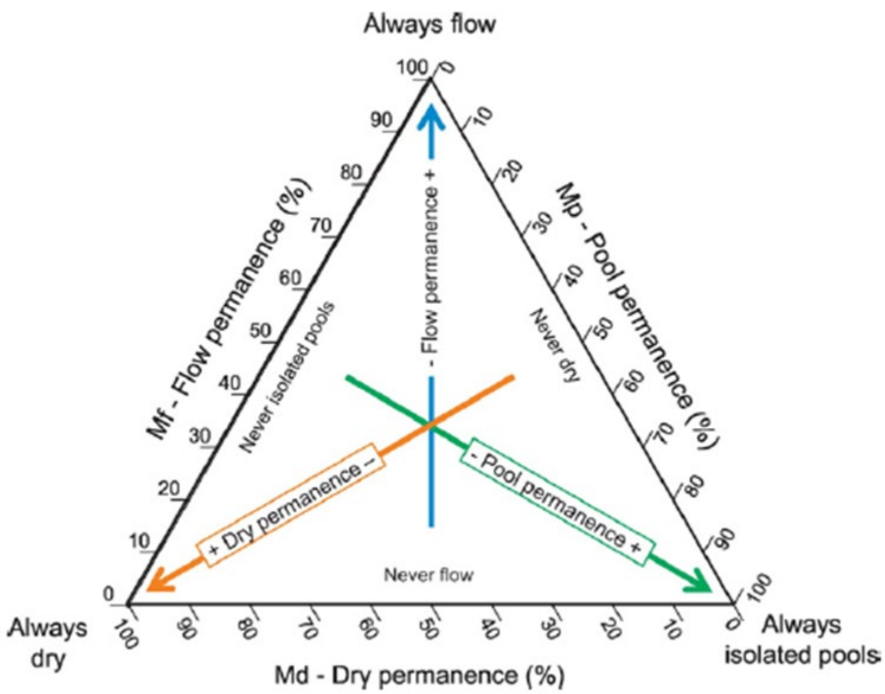
Prat et al. (2014) developed an assessment framework known as Mediterranean Intermittent River ManAGEment (MIRAGE) to identify the flow status of streams in order to guide selection of appropriate condition assessment tools based on biology, water chemistry, habitat, or other condition indicators. The first step in analysis is determining the flow duration of a stream using the Temporary Stream Regime Tool (TRS-Tool; Gallart et al. 2012, Gallart et al. 2017). The TRS-Tool uses three potential sources of flow estimation/observation to determine stream flow classification: 1) interviews, 2) interpretation of high-resolution aerial photographs and rapid field observation, and 3) outputs from hydrologic rainfall-runoff models.

In contrast with other methods, this assessment method classifies streams into more than three flow-duration classes, reflecting the predominant aquatic states, such as intermittent-pool, intermittent-dry, episodic-ephemeral or perennial.

Methodology for interviews is documented in Gallart et al. (2016). Interviews target locals encountered in the vicinity of a stream in question, who either live or tend land along the stream. The core interview consists of five key questions:

1. How often does flow cease?
2. During non-flowing months, are there pools and for how long?
3. When there is no surface water, is there water in the alluvium?
4. How frequently are flow/pools/dry riverbeds observed during each season?
5. Have any changes in flow regime been observed recently?

Rapid field observations and photographic interpretation focuses strictly on hydrologic indicators, such as presence of pools, riffles, or dry streambed over several visits. Interviews and observations allow for a finer categorization of different aquatic states that involve flow as well as disconnected pools and dry riverbed. These are represented by flow permanence (Mf), pool permanence (Mp), and dry-period permanence in Figure 11.



Arrangement of the three main metrics that correspond to the three aquatic phases; flow permanence (*Mf*), Isolated pools permanence (*Mp*) and dry river permanence (*Md*), in the FPD (Flow – Pools – Dry) graph. The arrows show the progression of every one of the three metrics whereas the axes show the values of every one of them. The central point represents a river that undergoes the three aquatic phases with the same frequency.

Figure 11. Relationship of aquatic phases to flow duration in Gallart et al. (2017).

3.16 Czech Republic

Straka et al. (2019) recently developed a "biodrought" index to classify streams as perennial or intermittent based strictly on the composition of benthic macroinvertebrate communities (Figure 12). Based on a data set of 23 streams in the Czech Republic (mostly in the Carpathian Mountains and Central Highlands) consisting mostly of paired perennial and non-perennial sites (both "intermittent" and "near perennial"), they identified indicator species associated with different flow regimes, and developed a seasonally-adjusted index consisting of three metrics that could discriminate between the three flow-regime classes (Table 7).

Table 7. Metrics in the Biodrought index developed by Straka et al. (2019).

Metric	Flow state indicated by high values
Proportion of indicator taxa (perennial indicators/ perennial + intermittent indicators)	Perennial
Proportion of taxa with high body flexibility	Intermittent
Preference for organic substrate (Autumn samples only)	Intermittent
Total abundance (Spring samples only)	Perennial

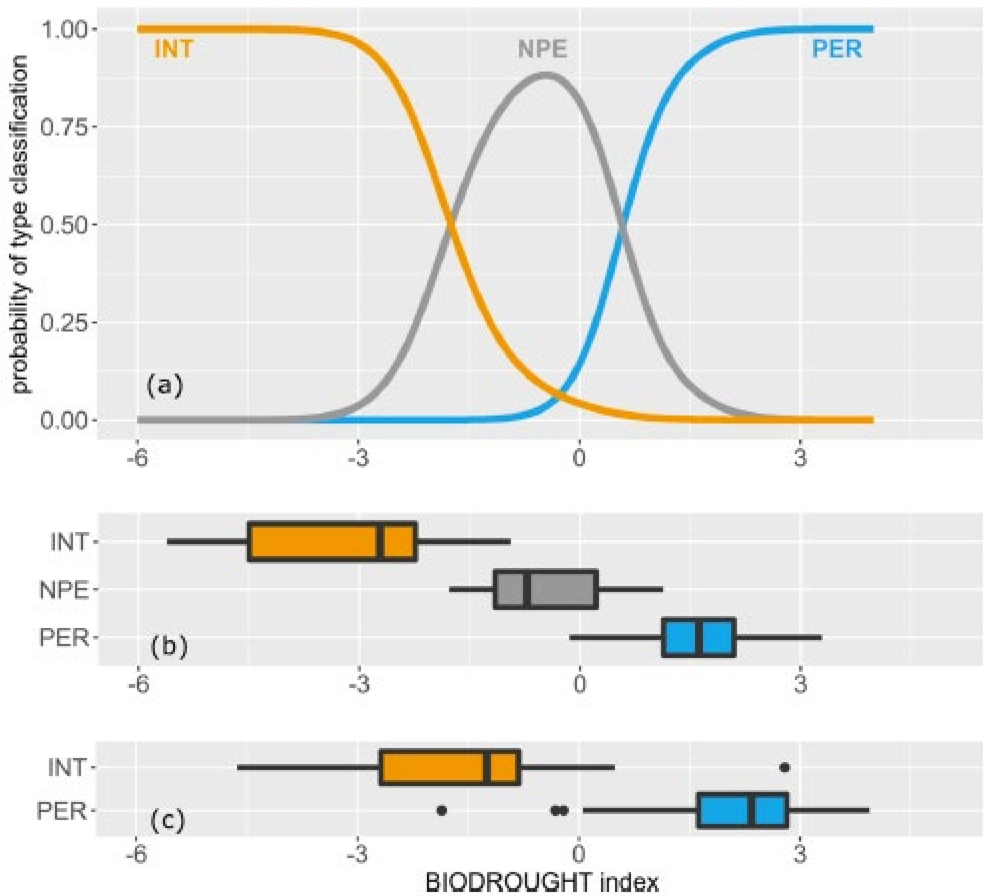


Figure 12. Relationship between biodrought index scores and flow classes, from Straka et al. (2019).Top panel shows the probability of classification as the index score increases. The second panel shows scores associated with calibration data. The bottom panel shows scores associated with independent validation data. INT: Intermittent. NPE: Near-perennial. PER: Perennial.

As with Nadeau (2015), the index of Straka et al. (2019) uses aquatic invertebrates to discriminate between perennial and intermittent streams, but not to discriminate ephemeral streams. But the two indices differ in a few important aspects. First, indicator taxa were identified at the species or genus level, which reduces the rapidness of this method if lab-based identifications are required. Second, indicator taxa were identified through an empirical method (i.e., indicator species analysis), whereas the indicators of Nadeau (2015) were derived from life history information and experience of stream ecologists in the Pacific Northwest (Blackburn and Mazzacano 2012) and through analysis of field collected data (Nadeau et al. 2015). Third, the biodrought index takes into account the presence of intermittent indicator taxa, whereas the method of Nadeau (2015) found superior performance when only perennial indicator taxa are considered. It is important to note that this index has not yet been validated.

3.17 Alberta, Canada (Foothills)

This method was developed for use in the forested Foothills region of Alberta to assign erosion-based stream classifications to headwater streams to better inform forest management decisions (McCleary et al. 2012). These classifications are largely based on dominant surface erosion processes, which are often driven by degree of flow permanence. The classes align with traditional flow duration categories as shown in Table 8.

Table 8. Erosion-based stream classes and corresponding flow duration class (adapted from McCleary et al. 2012).

Class	Best corresponding flow duration class	Class Description
Upland	Upland (none)	Surface erosion driven by overland flow and tree root throw; no depression or surface water present; usually vegetated, with non-hydrophytic species.
Swale	Ephemeral	Historic channel migration removed material and created a depression. Feature is vegetated, with hydrophytic species.
Discontinuous channel	Intermittent	Includes alternating sections of channel and vegetated ground. Channel may be actively migrating upstream or in recovery with encroaching vegetation, but vegetation will usually be limited or absent in the channel itself.
Seepage-fed channel	Intermittent, transitional, or small permanent	Channel with a continuous bed but insufficient stream power to transport larger streambed material; therefore, these channels generally lack typical bed features (e.g. regular riffle-pool sequence).
Fluvial channel	Small or large permanent	Channel with a continuous bed and sufficient amount of power to transport most material endemic to the area.

Simple observations (type, presence/absence of vegetation, continuity of channel) are used to distinguish the first two stream classes (not including upland) from each other and seepage-fed and fluvial channels. For seepage and fluvial channels, the indicators shown in Figure 13 are used to determine the class. This method is a simple way to distinguish ephemeral and discontinuous intermittent streams; however, for continuous channels, it is not able to distinguish intermittent from perennial streams.

Feature number	Seepage-fed channel features	Fluvial channel features
1	Fine bed material collected from deepest part of channel is mostly silt and organic matter. If required, use a hand texturing procedure to confirm[a].	Fine bed material collected from deepest part of channel is mostly well-sorted sand. If required, use a hand texturing procedure to confirm[a].
2	Unconsolidated bed along the deepest part of channel. Indicated if when standing on one foot, the surveyor's boot sinks to a depth > 10 cm.	Consolidated channel bed. Indicated if the surveyor's boot does not sink to a depth of > 10 cm.
3	No steps / riffles created by mobile gravel or cobbles[b].	Steps / riffles with regular spacing created by mobile gravel or cobbles[b].
4	No pools present[b].	Pools present with regular spacing[b].
5	Organic bridges present[b].	No organic bridges present[b].
6	Head cuts present[b and c].	No head cuts present[b and c].
7	Maximum bankfull width[d] >3x the minimum width.	Maximum bankfull width[d] <3x the minimum width.
8	Total undercut width[e] > bankfull width.	Total undercut width[e] < bankfull width.
Total	**See Section 3.1 for interpreting tally**	**See Section 3.1 for interpreting tally**

Figure 13. Characteristics of seepage-fed and fluvial channels in McCleary et al. (2012).

3.18 Idaho

Savage and Rabe (1979) classified lower order (1°-4°) streams in Idaho (and applicable to other Rocky Mountain states) based on physical, chemical, and biological differences. The five stream classes include ephemeral, spring-fed, and three types of permanent streams (categorized as '1', '2', and '3'). Ephemeral streams are described as only containing water during high runoff, though this characteristic appears to be the only one used to distinguish it from the other classes. Spring-fed streams have a major spring source, with little seasonal variation in discharge (likely perennial). The different types of permanent streams are largely distinguished by gradient (expressed as bedform pattern, e.g. riffle-pool vs. meandering-glide) and type of substrate. 'Permanent' streams, as described by the authors, have high seasonal variation in flow volume and intermittency, especially in the summer months, which appears to indicate that truly 'intermittent' streams are likely included in this category with non-spring-fed perennial streams. The biological community of the three types of permanent streams is also characterized, including vascular plants, algae, liverworts, benthic macroinvertebrates, amphibians, and fish. However, because intermittent streams are not separated from perennial streams in the permanent stream class, this system has low utility as a flow duration method.

4.0 INDICATORS IN THE NORTHEAST AND SOUTHEAST

A review of literature describing indicators in the NE/SE shows general support for indicators used in current flow duration assessment methods, particularly biological indicators. We discuss each class of indicators and determine whether specific indicators should be included in the evaluation of flow duration assessment methods in the NE/SE, with particular attention to the indicators included in NCDWQ (2010) and Nadeau (2015).

4.1 Geomorphological Indicators

All of the field SDAMs used in the NE/SE rely on geomorphological indicators to assess flow permanence (see Table 2). Fritz et al. (2008) explored what physical characteristics of forested headwater streams might best distinguish perennial, intermittent, and ephemeral flow types in the NE (see Section 3.2.2 for states) while also assessing the NC SDAM (2005 version; Section 3.2.1) and Ohio HHEI (Section 3.2.4) for applicability across a wider geographic range. This study included both 'dry' variables not reliant on water presence (e.g., modified versions of the NC and Ohio methods, drainage area, entrenchment ratio) and 'wet' variables (e.g. wetted width, max pool depth, unmodified NC and Ohio methods), though the latter were only used to discriminate between those sites with water present at least part of the year (intermittent and perennial reaches). Using 'dry' variables only, ephemeral sites were best distinguished from other sites in the 'core' study area (IN, KY, and OH) using drainage area and modified versions of the NC and Ohio methods employing only those indicators not reliant on water presence (many geomorphological). Similarly, mean entrenchment ratio was the best discriminatory 'dry' variable for distinguishing between intermittent and perennial sites. Regarding the field-based tools considered, the OH HHEI did a good job correctly classifying perennial sites (98%), though the success rate for intermittent and ephemeral sites was more modest (34% and 46%, respectively). Two geomorphological indicators, maximum pool depth and bankfull width, best distinguished ephemeral from the two other flow classes and vice versa, respectively. The NC method had a similar success rate to the OH method in classifying perennial sites but was better at classifying intermittent and ephemeral sites (43% and 82%, respectively). Two hydrological metrics (see below) were best at distinguishing ephemeral from intermittent and perennial sites using this method.

Using the same 'core' study area, Johnston et al. (2009) found that during the wet season (spring), a classification and regression tree (CART) model showed that maximum pool depth was the best at separating ephemeral sites from other flow types, while entrenchment ratio and catch per unit effort (CPUE) of larval Southern two-lined salamanders (*Eurycea cirrigera*) were somewhat less effective at separating perennial from intermittent streams. In the dry season (summer), salamander CPUE explained the most variation among sites in the CART model, followed by maximum pool depth, and bankfull depth and width. Both spring and summer models correctly classified approximately 80% of streams as ephemeral, intermittent, or perennial in the core study area; however, when these models were applied to validation data from 'satellite' sites (in IL, NH, NY, VT, and WA), the classification success rate for ephemeral and intermittent streams (85%) was much higher than the rate for perennial streams (20%).

Howard (2007) explored different geomorphic characteristics of ephemeral/intermittent and intermittent/perennial transitions in headwater streams in the Piedmont of NC. The data suggested a direct relationship of catchment area with sinuosity and an inverse relationship with valley and channel slopes. Since catchment or drainage area generally increases as streams progress from ephemeral to perennial, these relationships may help in predicting flow duration.

Tufa Deposits

In alkaline waters rich in carbonate, tufa deposits may form under certain conditions. Tufa deposition processes are highly dependent on physiochemical and biological factors not directly related to flow duration (Ford and Pedley 1996). For example, Ford and Pedley (1996) described areas throughout the US (including sites in the NE/SE) in which tufa formations occur, including fossil tufa sites, where historical conditions allowed for the formation of tufa but are no longer actively forming – meaning that tufa presence is not representative of the current present-day hydrologic conditions. No studies were found to support the use of tufa deposits as an indicator of flow duration, as the basis of their formation is not explicitly linked to flow duration and the presence of such formations is not an indicator of present-day stream flow. Observations of tufa formations in an ephemeral stream by Wright (2000) showed that minimal flow is needed for such formations, whereas flow obstructions can be the major factor affecting tufa formation in ephemeral streams. Other than Wright (2000), there were no other studies found that focused on describing connections between flow duration and tufa formation; rather, most research found aimed at understanding the physiochemical or biological processes that affect tufa formations.

4.2 Hydrologic Indicators

Several methods identified in this review use the prevalence and/or distribution of leaf litter/packs or drift/wrack lines (e.g., Topping et al. 2009, NCDWQ 2010) to distinguish between flow duration types. For leaf litter, these and other methods assign scores for this indicator based on an inverse relationship; that is, it is assumed that more leaf litter will be retained in ephemeral and intermittent channels due to prolonged absences of flow that might move leaf debris out of a reach. While Fritz et al. (2008) found that absence of baseflow was the most important variable in separating ephemeral from intermittent and perennial channels (see Section 4.1), the strong presence of the year's or the previous year's leaf litter in the streambed was the second most important.

In forested catchments in eastern Kentucky, Fritz et al. (2010) observed that the standing crop of coarse particulate organic matter was significantly higher in ephemeral channels than perennial and intermittent channels. Leaf litter might be expected to persist longer in these environments partially due to absence of flow, but also because leaf decomposition rates are slower. For instance, in this same study, the decomposition rate of white oak (*Quercus alba*) leaves were found to be significantly faster in perennial and intermittent streams than in ephemeral streams, which was correlated with macroinvertebrate shredder richness in leaf packs. Similarly, Northington and Webster (2017) found that white oak and red maple (*Acer rubrum*) leaves in western NC had slower breakdown rates in ephemeral reaches and other sampled habitats (bank, upslope) that were not permanently wet.

Mersel and Lichvar (2014), in their guide to Ordinary High Water Mark (OHWM) delineation for non-perennial streams in the Western Mountains, Valleys, and Coast Region, identify wrack lines/drift deposits as a supporting feature for finding the location of the OHWM in these environments. While OHWM delineation and flow duration are two different concepts, wrack lines and other organic debris accumulations (including large woody debris) still indicate the presence of water flow, though they may only be remnants of individual flow events rather than ordinary or regularly occurring conditions. For instance, in Kentucky, Fritz et al. (2019) showed that while ephemeral tributaries store and export leaf litter and small wood for several months after autumnal leaf abscission, the amount of organic litter transported and deposited downstream each month was related to peak magnitude of rainfall, not differences in duration or frequency of flows.

In the WM literature review, large woody jams (also called “debris jams”) are identified as an important component of streams in the WM, with several studies investigating the impacts of large woody jams on stream ecology, stream channel morphology, water velocity, and to a lesser extent, flow duration. Given that the NE/SE contains mountainous terrain and is also naturally forested, these studies may also apply to this region, though no specific studies from the NE/SE were found during the literature review, except for Mason Jr. et al. (1990). In the WM, there were conflicting reports of effect (Gippel 1995; Mason Jr. et al. 1990; Faustini & Jones 2003; Shields & Gippel 1995) versus no effect (Matheson et al. 2017; Lester & Wright 2009) on the influence of organic jams (flow obstructing large woody debris) on flow duration, but several studies did consistently support the direct influence of jams on modifications of other stream flow duration indicators – e.g., Abbe and Montgomery (1996), Faustini and Jones (2003) and Smith et al. (1993) showed significant differences in gradient, bank morphology and pool frequency along stream reaches pre- and post-jam removal. In a review of hydrologic effects of large woody jams, Gippel (1995) shows that their presence can have an indirect slowing effect on flow conveyance via increases in channel roughness and increases in channel stage height. Several studies have documented the prevalence of large woody jams in WM streams (Mersel and Lichvar 2014), and although there is little evidence to support direct hydrologic influence of debris jams, the other processes they affect support its evaluation as a potential indicator of flow duration.

4.3 Biological Indicators

In contrast to the many of the other indicators mentioned above, biological indicators are often directly related to flow duration. Consequently, many studies corroborated relationships between these indicators and flow duration, particularly aquatic macroinvertebrates and vertebrates. Also included here are discussions of studies from the AW, WM, and GP since biological indicators can be widespread; if a study is specific to the NE/SE, it is indicated as such.

4.3.1 Aquatic macroinvertebrates

In general, studies provide strong support for the use of aquatic invertebrates as indicators of flow duration. However, it is also important to note that there is evidence that taxa occurrence occurs along a gradient of flow permanence and the presence of certain taxa may not be an indicator of flow duration by itself (Beugley and Pyron 2010, Feminella 1996, Chadwick et al. 2012, Collins et al. 2007, Grubbs 2011). Although training is required, field-based family level identifications are practical for aquatic macroinvertebrates, further underscoring their suitability as indicators. The Pacific Northwest SDAM (Nadeau 2015) uses a list of macroinvertebrate flow duration indicators developed by the Xerces society (i.e., Mazzacano and Black 2008, Blackburn and Mazzacano 2012) in its flow duration decision tree. Similarly, the NC SDAM (NCDWQ 2010) uses a list of perennial indicator taxa (PIT; NCDWQ 2005) as support for perennial stream determinations even when the stream score is lower than the perennial threshold. The lists have many similarities, though there are important differences as well (Table 9). In general, the NC method includes more taxa than the PNW method and includes several mayfly (Ephemeroptera) taxa whereas the PNW has no mayfly PIT and instead uses a measure of abundance. Some of the differences between the two lists may be explained by species' distributions (e.g., with Margaritiferidae and Hydrobiidae) or how widespread species of that taxon are in each region.

Table 9. Comparison of the perennial indicator taxa used in the Pacific Northwest and NC SDAMs (Blackburn and Mazzacano 2012; NCDWQ 2010). Note: larval indicators are for late-instar stages only.

Taxa	PNW Method Perennial Indicator Families	NC Method Perennial Indicator Families
Ephemeroptera (larvae)	No indicator families; uses abundance of Ephemeroptera (6 or more individuals)	Baetidae, Caenidae, Ephemerellidae, Ephemeridae, Heptageniidae, Leptophlebiidae, Siphlonuridae
Plecoptera (larvae)	Pternarcyidae, Perlidae	Peltoperlidae, Perlidae, Perlodidae
Trichoptera (larvae)	Philopotamidae, Hydropsychidae, Ryacophilidae, Glossosomatidae	Philopotamidae, Hydropsychidae, Ryacophilidae, Lepidostomatidae, Limnephilidae, Molannidae, Odontoceridae, Polycentropidae, Psychomyiidae
Coleoptera (larvae)	Elmidae, Psephenidae	Elmidae, Psephenidae, Dryopidae (*Helichus* adults only)
Odonata (larvae)	Gomphidae, Cordulegastridae, Calopterygidae, Corydalidae	Gomphidae, Cordulegastridae, Calopterygidae, Aeshnidae, Libellulidae
Megaloptera (larvae)	Corydalidae	Corydalidae, Sialidae

Taxa	PNW Method Perennial Indicator Families	NC Method Perennial Indicator Families
Mollusca (any life stage)	Unionidae, Ancylidae, Pleuroceridae, Hydrobiidae, Margaritiferidae	Unionidae, Ancylidae, Planorbidae, Pleuroceridae; presence of Sphaeriidae only requires at least an 18 on geomorphology section of NCDWQ stream form
Diptera (larvae)	None	Ptychopteridae, Tipulidae (*Tipula* sp. only)
Crustaceans (any life stage)	None	Crayfish in channel; if only crayfish are present, require at least an 18 on geomorphology section of NCDWQ stream form

Studies conducted in the NE/SE that compared or characterized community composition and/or abundance of macroinvertebrates (including aquatic insects and worms, crustaceans, and mollusks) in perennial streams and those with shorter flow durations were found during this literature review and are summarized in Table 10. These studies present their results at different taxonomic resolutions, ranging from genus and species to family level or higher.

Table 10: NE/SE studies of aquatic macroinvertebrates in different flow duration classes.

Source	Region	Notes	Perennial/Permanent	Intermittent/ Ephemeral/Drought Conditions
Adams et al. (2018)	North-central Mississippi	Crayfish occurrence in intermittent vs. perennial streams		CPUE of *Hobbseus yalobushensis* (Cambaridae) was significantly greater in intermittent streams than perennial streams, mainly due to lack of predatory fish
Beugley and Pyron (2010)	East-central Indiana	Assessed macroinvertebrate assemblage in perennial and 'seasonal' streams	Study did not detect any effect of seasonal drying on invertebrate assemblages	
Chadwick et al. (2012)	Northeast Florida	Compared macrobenthic communities between urban and rural perennial and intermittent streams	Associated taxa: *Gomphus, Erthrodiplax, Melanoides*. Very few species were found in only one or the other flow regime (exceptions noted)	Associated taxa: *Campeloma*, unidentified Cambaridae
Collins et al. (2007)	North-central Massachusetts	Compared macroinvertebrate community using sub-surface flow paths with reaches having perennial surface flow		Sub-surface flow path had lower macroinvertebrate richness and abundance than paired perennial reaches. In this study, members of Elmidae, Hydrophilidae, and Hydropsychidae were found only in subsurface habitats
Courtwright and May (2013)	Northwest Virginia	Characterized macroinvertebrate community in intermittent streams		Associated taxa: Leptophlebiidae, Leuctridae, Chironomidae
Davis et al. (2003)	South-central Georgia (Suwannee River basin)	Compared macroinvertebrate community in intermittent streams over a range of conditions		Most common taxa: Dipterans, isopods (Lirceus, Caecidotea), amphipods (Crangonyx), oligochaetes, copepods, *Physella*, and pelecypoda (*Pisidium*; pea clam)

Source	Region	Notes	Perennial/Permanent	Intermittent/ Ephemeral/Drought Conditions
DeJong and Canton (2013)	West Virginia	Compared macroinvertebrates found in intermittent and ephemeral reaches with NCDWQ list of 'long-lived aquatic taxa' or PIT (see Table 9)		Representatives of Elmidae (*Oulimnius latiusculus*) and craneflies (*Tipula* sp.) were found, though in the case of *O. latiusculus* was probably a result of recent colonization
Delucchi (1988)	South-central New York	Compared macroinvertebrates found in riffle and pool habitats of perennial, intermittent, and 'dry' streams of different sizes	18 taxa only found in habitats that never dried (approx. 30% mayflies), including *Isonychia, Tricorythodes, Taeniopteryx, Hydroptila, Oreodytes*, and *Cordulegaster* 13 taxa reduced or eliminated by drying (approx. 50% caddisflies), including *Cheumatopsyche, Dolophilodes, Baetis, Ephemerella, Optioservus, Acroneuria*, and *Glossosoma*	Associated taxa (intermittent): *Pseudostenophylax, Cymbiodyta, Molanna,* and *Ptychoptera* Associated taxa ('dry'): oligochaeta, *Tipula*, chironomidae
DiStefano et al. (2009)	Southwest Missouri	Documented crayfish use of intermittent streams		*Orconectes* (aka *Faxonius*) *williamsi* and *O. meeki meeki* were able to persist in intermittent streams through 3 episodes of prolonged seasonal drying. Both species used the hyporheic zone during these periods
Eaton and Vander Vorste (2012)	Headwater streams in Alabama, Georgia, Florida, Kentucky, Mississippi, Tennessee, and South Carolina	One goal of the study was describe macroinvertebrate composition of perennial and intermittent streams, including a comparison with NCDWQ's PIT (see Table 9)	Number of NC PIT were significantly higher in perennial streams compared to intermittent streams, with twice as many PIT found in streams scoring over 30 on the NCDWQ stream form (perennial threshold).	Of NCDWQ PIT, the following were also found in intermittent streams: *Tipula* sp., and members of Leptophlebiidae, Siphonlonuridae, Corydalidae, Aeshnidae, Libellulidae, Perlidae, Perlodidae, all Trichopteran families (except Molannidae, Odontoceridae, and Psychomyiidae), Planorbidae, and Ancylidae.

Source	Region	Notes	Perennial/Permanent	Intermittent/ Ephemeral/Drought Conditions
Feminella (1996)	Alabama (Talladega National Forest)	Compared benthic macroinvertebrate assemblages in small perennial and intermittent streams. 75% of taxa showed no pattern of occurrence with flow duration	Species found in streams with higher permanence (normally perennial, occasionally and rarely intermittent) include *Stenonema, Ophiogomphus, Taeniopteryx, Pteronarcys, and Rhyacophila*	Species restricted to normally intermittent streams include *Hexagenia, Ochrotrichia, Tipula*, and *Corydalus*
Flinders and Magoulick (2003)	Northern Arkansas and southern Missouri	Explored effects of flow duration on crayfish communities		Crayfish density greater in intermittent vs. perennial streams; density of *Faxonius* (née *Orconectes*) *marchandi* and *F. punctimanus* were significantly greater
Golladay et al. (2004)	Southwest Georgia (Flint River basin)	Mussel response to record drought conditions in normally perennial streams that dried completely or with pools only		Substantial declines in mussel abundance and survival in non-flowing streams. However, at some sites, substantial numbers of *Elliptio complanata/icterina*, *Villosa lienosa*, and *V. villosa* survived, perhaps due to presence of woody debris creating pools and other habitat that did not dry completely
Grubbs (2011)	Eastern Kentucky	Compared macroinvertebrate communities in perennial vs. temporary streams (as defined by Svec 2003; see Table 2)	Total number of taxa, number of EPT taxa, filtering-collector, and gathering taxa richness as well as scaper and filtering-collector densities were significantly greater in perennial channels. More taxa showed increased abundances in perennial vs. temporary channels	Taxa that require water through summer were found in temporary channels (largely Plecoptera and Trichoptera). Certain taxa displayed increased abundances in temporary channels, but none appeared to be indicative of a temporary flow duration
Haag and Warren (2008)	Northern Alabama	Mussel response to record drought conditions in normally perennial streams that were reduced to interstitial or no flow		Unionid mussels and *Corbicula fluminea* abundances showed 60-83% declines after severe drought. No species were found to be more drought tolerant than others

Source	Region	Notes	Perennial/Permanent	Intermittent/ Ephemeral/Drought Conditions
Kelso (2012)	Northern Arkansas	Explores differences in macroinvertebrate communities of perennial and intermittent streams. No species were identified as significant indicators of flow duration	Associated taxa*: Psychomyia, Stylogomphus, Argia, Cheumatopysche, Isonychia*, and Sphaeriidae	Associated taxa: *Acentrella, Alloperla*, *Amphinemura, Acroneuria, Helicopsyche, Belostoma, Chrysops, Gomphus*, Dytiscidae, amphipods, and isopods
Kelso and Entrenkin (2018)	North-central Arkansas	Explores differences in macroinvertebrate communities of perennial and intermittent (7 mos. or 9 mos. flow) streams.	Associated taxa: *Isonychia, Neoperla, Chauliodes, Hagenius, Haploperla, Ordobrevia, Tabanus, Hansonoperla*, and Sphaeriidae	Associated taxa: *Chrysops,* Collembola*, Rhyacophila, Hexagenia, Molophilus* (7-mon FD) *Caloparyphus, Helichus* (9-mon FD)
Lubbers (2009)	Hamilton County, Ohio	Compared macroinvertebrate communities in streams along a flow permanence gradient in urbanized settings. Some abundances higher in streams with higher permanence scores, but no differences in community composition	High abundances of Orthocladiinae genera (chironomids), especially in the spring	
Santos and Stevenson (2011)	Northeastern Massachusetts	Explores differences in macroinvertebrate communities of perennial, intermittent (up to 4 mos. no flow), ephemeral (4 or more mos. no flow)	Associated taxa: *Chimarra, Ephemerella, Sialis*, and *Stylogomphus*	Intermittent associated taxa: *Isoperla, Helius, Molanna*, and *Lype* Ephemeral associated taxa: *Ironoquia, Glossosoma, Amphinemoura, Ameletus, Ptilostomis*, and *Nemoura*
Smith et al. (2017)	Southwest Georgia (Flint River basin)	Explores differences in macroinvertebrate communities of perennial, near perennial (cease flow in drought), intermittent-dry (seasonal), and intermittent-frequent (dry multiple times a year) streams. Associated taxa have an FD indicator value >60.	Mean insect and EPT richness significantly greater in perennial and near-perennial reaches Associated taxa (perennial and near-perennial): *Hydropsyche, Chimarra, Stenelmis, Plauditis, Hydroptila, Microcylloepus, Ancyronyx, Maccaffertium, Hemerodromia*	Associated taxa (intermittent-dry): *Gammarus*, Isopoda, Ancylidae, and Ostracoda Associated taxa (intermittent-frequent): 4 indicator taxa, only one above 60 (*Macromia*). Others include Physidae, Hirudinea, and Chironomidae
Williams and Taylor (2003)	Arkansas	Characterized macroinvertebrate community of an intermittent stream (to family only)		Most common family of macros (in pools and/or fish guts) were Heptageniidae and Chironomidae

Source	Region	Notes	Perennial/Permanent	Intermittent/ Ephemeral/Drought Conditions
Yarra and Magoulick (2018)	Arkansas and Missouri (Upper White River drainage)	Characterized crayfish community in permanent and intermittent streams	*Faxonius luteus* and *F. neglectus* had signficantly greater densities in permanent streams, though could be found in both stream types	*F. meeki meeki* and *F. williamsi* densities significantly greater in intermittent streams. In the case of *F. m. meeki*, this species was found only in intermittent streams

Below, major groups of aquatic macroinvertebrates are considered in relation to flow duration; though studies concentrate on the NE/SE, they may also draw from the AW, WM, and GP, where applicable.

Mollusks

In the AW and WM literature reviews, there was generally strong support for the perennial indicator status of mollusks (e.g., Lusardi et al. 2016), particularly for the New Zealand mudsnail (*Potamopyrgus antipodarum*), a non-native invader in streams throughout the West (e.g., Herbst et al. 2008, Bogan et al. 2013), though this species is not yet found in any great numbers in the NE or SE. Straka et al. (2019) identified this taxon as an indicator of intermittent or nearly perennial Czech streams, along with numerous taxa in Physidae, Planorbiidae, and Lymnaeidae. A number of Lymnaeid taxa were also indicators of perennial flow, along with *Ancylus fluviatilis* (Planorbiidae). In the NE/SE, studies did not necessarily support the inclusion of Planorbidae and Ancylidae as PIT (Eaton and Vander Vorste 2012, Smith et al. 2017), though Eaton and Vander Vorste (2012) observed members of Physidae and Lymnaeidae only in perennial streams. However, Davis et al. (2003) also found Physid snails (*Physella* sp.) in streams with less than perennial flow, which is consistent with studies in the GP (Bramblett and Fausch 1991, King et al. 2015, and Miller and Golladay 1996).

Although they are less widespread than many gastropods, freshwater mussels are also likely to be good indicators of perennial flow, though species in the Unionidae family (widespread in North America) have been shown to survive prolonged periods of drying (Alyakrinskaya 2004). However, Golladay et al. (2004) and Haag and Warren (2008) found that a prolonged drought event along the Gulf Coastal Plain, where normally perennial streams dried or flow was substantially reduced, resulted in significant declines in unionid mussel and *Corbicula fluminea* (Asian clam) abundance and survival. While Golladay et al. (2004) found that certain mussel species had better survival rates through the drought, it appears this result was largely due to bedform complexity provided by large woody debris rather than any sort of drought tolerance. Fingernail clams (Sphaeriidae) are not generally treated as a perennial indicator taxon, at least without other evidence the stream is perennial (NCDWQ 2010). However, some support for this classification is found in Lusardi et al. (2016), Kelso (2012), and Kelso and Entrenkin (2018). However, Straka (2019) identified *Pisidium* (pea clams) as an indicator of intermittent flow, and Davis et al. (2003) found this taxon in intermittent streams in Georgia.

Ephemeroptera (mayflies)

No mayfly families are considered to be an indicator of perennial flow in Blackburn and Mazzacano (2012), though NCDWQ identifies several as PIT (Table 9). Of these, Eaton and Vander Vorste (2012) found representatives of Baetidae, Caenidae, Ephemerellidae, Ephemeridae, and Heptageniidae only in perennial headwater streams across several states in the NE/SE. This finding is supported by Delucchi (1988), Santos and Stevenson (2011), and Smith et al. (2017). However, Kelso and Entrenkin (2018) and Feminella (1996) found *Hexagenia* sp. (Ephemeridae) to be indicative of, or largely restricted to, intermittent flow. Kelso (2012) observed *Acentrella* (Baetidae) in intermittent streams, though it was not considered a significant indicator. Williams and Taylor (2003) found that Heptageniidae was one of the most common families of macroinvertebrates in intermittent stream pools.

While NCDWQ (2010) also lists Leptophlebiidae and Siphonlonuridae as perennial indicator Ephemeroptera, Eaton and Vander Vorste (2012) found members of these families in intermittent, as well as perennial streams. This finding is also supported by Courtwright and May (2013), at least for Leptophlebiidae. However, a few studies in the Great Plains support Leptophlebiidae as a perennial indicator (Fritz and Dodds 2002, Miller and Golladay 1996, and Harris et al. 1999). NE/SE studies found for this review also suggest that Isonychidae may show a preference for perennial flow (Delucchi 1988, Eaton and Vander Vorste 2012, Kelso 2012, Kelso and Entrenkin 2018).

Studies from other regions support Baetidae as a perennial indicator (e.g., Bonada et al. 2006, Miller and Golladay 1996, Harris et al. 1999), while others suggest they prefer intermittent flow (e.g., Miller and Brasher 2011) or can be found in both flow types (Stagliano 2005). Straka et al. (2019) found numerous mayfly indicator taxa of both intermittent/nearly perennial streams (e.g., *Cloeon dipterm*) and perennial streams (e.g., *Baetis rhodani*).

<u>Plecoptera (stoneflies)</u>

Both the PNW and NC methods utilize Perlidae as a PIT, though Eaton and Vander Vorste (2012) found one member of this family in both intermittent and perennial streams (*Perlesta* sp.). Several studies within and outside the NE/SE support the use of perlid stoneflies as indicators of perennial flow (e.g., Bonada et al. 2006, Lusardi et al. 2016, Bogan 2017, Delucchi 1988, Kelso and Entrenkin 2018), but a few studies report them in intermittent streams, usually at low abundances (e.g., del Rosario and Resh 2000, Miller and Golladay 1996, Kelso 2012). Perlodidae and Peltoperlidae, which are also considered PIT by NCDWQ, were not well-represented in the NE/SE literature except for Santos and Stevenson (2012) that found *Isoperla* sp. (Perlodidae) associated with intermittent streams. One species of *Isoperla* (*bilineata*) was also observed by Eaton and Vander Vorste (2012) in both intermittent and perennial streams, though the remaining species identified in this genus (5 of 6) were collected only from perennial streams. The PNW method (Nadeau 2015) also uses Pteronarcyidae as a PIT, though few to no studies in the AW, WM, GP, or NE/SE indicated if members of this family were collected, suggesting that this taxon may be too rare to be a useful indicator in these regions. One exception in the NE/SE was Feminella (1996), who found *Pteronarcys* sp. in normally perennial streams (only occasionally or rarely intermittent).

In Czech streams, Straka et al. (2019) identified four indicators of intermittent flows (in Taeniopterygidae, Capniidae, Perlodidae, and Nemouridae), and numerous indicators of perennial flow (species in Nemouridae, Perlidae, Perlodidae, Chloroperlidae, and Leuctridae). One *Isoperla* species (i.e., *I. tripartita*) was an indicator of intermittent flows, whereas two species (i.e., *I. oxlepis* and *I. rivularum*) were indicators of perennial flows, suggesting that even genus-level identifications may be too coarse to provide meaningful indication of flow duration, which mirrors results in Eaton and Vander Vorste (above). In the NE/SE, Kelso (2012) and Santos and Stevenson (2011) found members of the Nemouridae (*Amphinemura* sp. and *Nemoura* sp.) to be associated with intermittent or ephemeral streams, respectively.

Trichoptera (caddisflies)

Several Trichopteran families are used as PIT in the NC method, though only three were found exclusively in perennial streams in Eaton and Vander Vorste (2012), including Molannidae, Odontoceridae, and Psychomyiidae. These results are supported by Kelso (2012), who found *Psychomyia* sp. exclusively in perennial streams, but are in contrast with Santos and Stevens (2011) that found *Lype* sp. (Psychomiidae) as indicators of intermittent flow. In addition, Delucchi (1988) and Santos and Stevenson (2011) found *Molanna* sp. associated with intermittent streams. It should be noted that, out of 12 species identified, only 3 Hydropsychidae identified by Eaton and Vander Vorste (2012) were found in both intermittent and perennial streams (species of *Homoplectra* and *Diplectrona*), so this taxon is generally a PIT. Only one study in the NE/SE (Smith et al. 2017) identified hydropsychid caddisflies (*Hydropsyche* sp.) as a perennial indicator, but in the WM and GP, five studies supported the use of this family as a PIT (Bramblett and Fausch 1991, Burk and Kenndedy 2013, Fritz and Dodds 2002, Miller and Brasher 2011, and Stagliano 2005).

Two other families identified as PIT by NCDWQ (Philopotamidae and Rhyacophilidae) are supported as indicators of perennial flow outside the NE/SE (Bonada et al. 2006, Erman and Erman 1995, Burk and Kennedy 2013, and Miller and Golladay 1996). In the NE/SE, *Rhyacophila* species are found in both normally perennial streams (Feminella 1996) and intermittent streams (Kelso and Entrenkin 2018), and species both exclusive and non-exclusive to perennial streams were recorded by Eaton and Vander Vorste (2012). Members of Philopotamidae (*Chimarra* sp., *Dolophilodes* sp.) were found as indicative of perennial flow in Delucchi (1988), Santos and Stevenson (2011), and Smith et al. (2017). Limnephilidae are also considered a PIT by NCDWQ, though Eaton and Vander Vorste (2012) specifically note that *Ironoquia* and *Pseudostenophylax* genera are likely not indicative of perennial flow, which is supported by Santos and Stevens (2011) and Delucchi (1988), respectively.

In parts of the WM, several studies suggested that additional families, such as Brachycentridae or Calamoceratidae, may also be good perennial flow indicators (Bonada et al. 2006, Miller and Brasher 2011). Staka et al. (2019) identified a handful of indicator species for intermittent flows in Czech streams (Beraeidae, Phryganeidae, and numerous species in Limnephilidae), and numerous indicators of perennial flows in several families (including Glossosomatidae, Hydropsychidae, Limnephilidae, Phryganeidae, Polycentropidae, and Rhyacophilidae).

Coleoptera (beetles)

Both Elmidae and Psephenidae are used as PIT in Nadeau (2015) and NCDWQ (2010). Several studies in the NE/SE indicated that elmid beetles showed a strong preference for perennial streams (Delucchi 1988, Eaton and Vander Vorste 2012, Santos and Stevens 2011, Smith et al.

2017), though they are occasionally found in intermittent reaches as well (DeJong and Canton 2013, Burk and Kennedy 2013)—particularly if they are close to perennial waterbodies. In the AW, De Jong et al. (2013) note that *Optioservus quadrimaculatus* and *Zaitzevia parvula* are comparatively well-adapted to colonize intermittent streams shortly after rewetting. Psephenidae are supported as an indicator of perennial flow in Eaton and Vander Vorste (2012), as well as Bonada et al. (2006) and King et al. (2015) outside the NE/SE.

Several aquatic beetle families could be indicators of intermittent flow (e.g., Hydrophilidae: Bonada et al. 2006, Bogan and Lytle 2007), and some are documented from ephemeral streams (De Jong et al. 2015). Straka et al. (2019) identified several indicators of intermittent flow in Czech streams (mostly Dytiscidae, Hydrophilidae, Helophoridae, and Hydraenidae), as well perennial streams (several Elimdae, as well as Dytiscidae, Gryinidae, Hydraenidae, and Scirtidae).

Odonata (dragonflies and damselflies)

Several studies within and outside the NE/SE support the use of Gomphidae and Cordulegastridae as indicators of perennial flow (e.g., Bonada et al. 2006, King et al. 2015, Straka et al. 2019, Chadwick et al. 2012, Delucchi 1988, Feminella 1996). Except for one unidentified *Cordulegaster*, Eaton and Vander Vorste (2012) found all collected members of these families associated with perennial streams. They also found both Calopterygidae species (two genera) observed to be associated only with perennial streams, in agreement with Fritz and Dodds (2002) in the GP. Straka et al. (2019) identified a Coenagrionidae species to be indicative of intermittent flows in Czech streams, though Kelso (2012) and Fritz and Dodds (2002) found *Argia* sp. to be associated with perennial streams. Chadwick et al. (2012) observed *Erthrodiplax* (Libellulidae) in perennial streams only, though Eaton and Vander Vorste (2012) observed other members of this family in both perennial and intermittent streams (e.g. *Pachydiplax, Libellula*).

Megaloptera (dobsonflies, alderflies)

Corydalidae are listed as an indicator of perennial streams in both Blackburn and Mazzacano (2012) and NCDWQ (2010) but some reports from montane regions in the arid southwest (e.g., Bogan and Lytle 2007) considered them to be indicative of intermittent conditions. Cover et al. (2015) describes two genus-groups within this family: The *Neohermes-Protochauliodes* group, which is well adapted to intermittency by building hyporheic aestivation chambers to survive the dry period (Figure 14), and the *Orohermes-Dysmicohermes* group, which does not burrow and is therefore restricted to perennial streams. Distinguishing the two genus-groups in the field may be possible, as the *Neohermes-Protochauliodes* group has distinctive head patterns in late instars (M. Cover, personal communication). Eaton and Vander Vorste (2012) found one *Chauliodes* in both perennial and intermittent streams, though Kelso and Entrenkin (2018) observed this genus in perennial streams only, while Feminella (1996) found *Corydalus* sp. in normally intermittent streams only. NCDWQ also includes Sialidae as a PIT, which is supported by Eaton and Vander Vorste (2012) and Santos and Stevenson (2011).

Figure 14. Neohermes aestivation chamber in a dry streambed in Arizona; the red box indicates the area shown in the right photo (courtesy M.T. Bogan).

Diptera (true flies, craneflies)

Unlike Mazzacano and Black (2012), NCDWQ (2010) includes dipteran PIT, Ptychopteridae and *Tipula* sp. Eaton and Vander Vorste (2012) found Ptychopteridae only in perennial steams; however, Delucchi (1988) observed *Ptychoptera* sp. to be associated with intermittent streams. *Tipula* sp. was also found to be linked to intermittent and drier conditions in several studies in the NE/SE (DeJong and Canton 2013, Delucchi 1988, Feminella 1996). Cañedo-Argüelles et al. (2016) suggest that the diverse genera within Chironomidae may have strong preferences for certain flow duration conditions, which is supported by several studies from other regions (e.g., Bonada et al. 2006, Miller and Brasher 2011). Herbst et al. (2019) found numerous midge taxa associated with perennial flows, while other taxa were associated with intermittent flows. In the NE/SE, Chironomidae were usually associated with intermittent or drier flow regimes (Delucchi 1988, Smith et al. 2017, Williams and Taylor 2003) and were one of the most abundant and cosmopolitan taxa in both perennial and intermittent streams in the GP (Miller and Golladay 1996, Vander Vorste et al. 2008, Vander Vorste 2010). Fritz and Dodds (2002) also found that families in the Brachycera suborder (Phoridae, Sepsidae, and Scathophagidae) were generally associated with intermittent streams. However, challenges with identifying this group in the field may make them impractical for use in a field-based flow duration assessment method.

Other aquatic invertebrates

NCDWQ utilizes crayfish as a PIT, though its use must be supported by other evidence the stream is perennial (Table 9). Studies involving this taxon in the NE/SE mostly show that crayfish density is generally higher in intermittent versus perennial streams, which appears mainly due to a decrease in predatory fish due to drying (Adams et al. 2018, Flinders and Magoulick 2003, Yarra and Magoulick 2018). DiStefano et al. (2009) observed that crayfish species in southwest Missouri were able to persist in these streams through numerous bouts of seasonal drying, which appeared to be promoted by their use of the hyporheic zone. Most studies did not show a preference of certain species for one flow regime, though Yarra and Magoulick (2018) did find *Faxonius meeki meeki* in intermittent streams only.

In their study of Czech streams, Straka et al. (2019) identified several non-insect indicators of intermittent streams, including the flatworm *Mesastoma*, the nematomorph *Gordius*, several oligochaetes and leeches, and the isopod *Asllus aquaticus.* They also found numerous non-insect indicators of perennial flows, such as several flatworm species (e.g., *Dugesia, Polycelis*) , several oligochaetes and leeches, the Hydracarina mites, and the amphipod *Gammarus fossarum*. Smith et al. (2017) found *Gammarus* sp., isopods and ostracodes to be largely associated with intermittent streams. In Stagliano (2005), a suite of crustaceans is given as indicative of intermittent stream ecosystems in the northern GP that have fishless pools. These taxa (fairy, clam, and tadpole shrimps, ostracodes, copepods, and cladocerans) have resting egg stages that can resist dry periods of a year or more. However, most of the indicative taxa are small and likely hard to identify easily in the field, though the shrimps may allow for field sampling/identification.

4.3.2 Algae

Algal biofilm, mats and other macroalgal forms are evident in most streams within a week of the onset of flow (even 1 day, in the case of biofilms), and thus their presence may not always be a good indicator of perennial or intermittent flow (Benenati et al. 1998, Robson et al. 2008, Corcoll et al. 2015). However, most studies suggest that macroalgal growth in the first two weeks may be limited, particularly in hydrologically isolated systems without access to perennial refugia (Robson et al. 2008). Thus, the abundance, rather than the presence of macroalgae may be an effective indicator of flow duration.

Taxonomic identity for most algal species is difficult to ascertain in the field, and they are therefore ill suited for use as a field-based flow duration indicator. However, several studies suggest that there are flow-duration affinities for several groups. For example, Benenati et al. (1998) showed that the macroalga *Cladophora* tend to dominate in perennial streams, while diatoms and the filamentous cyanobacterium *Oscillatoria* dominate in intermittent streams. Certain macroalgae groups are readily identifiable in the field (Entwisle et al. 1997), potentially providing sufficient information to inform flow duration assessment.

Dormant algal propagules may accumulate in the dry streambed and be resuscitated in lab conditions. This approach has been proposed as a way to assess ecological conditions of dry lakes and streambeds (Carvalho et al. 2002, Robson 2008), and could be used to assess flow duration. But because of the intensive nature of this approach, it is not well suited for a rapid flow duration assessment method.

4.3.3 Bryophytes

The presence of "streamer mosses" is an indicator of intermittent or perennial flow duration in Topping et al. (2009). Several studies support this use (Fritz et al. 2009, Cole et al. 2010), and a number of taxa have been designated in terms of moisture preferences (e.g., Appendix A in Fritz et al. 2009). Vieira et al. (2012, 2016) identified bryophyte community types characteristic of intermittent and perennial rivers in Mediterranean Europe. They found that intermittent rivers were dominated by drought tolerant taxa (e.g., *Scorpiurium*), and upright acrocarpous annual forms, while perennial streams had more prostrate pleurocarpic perennial mats.

4.3.4 Wetland and Riparian Vascular plants

The presence of wetland indicator plants is an important indicator of flow duration in several methods (e.g. NCDWQ 2010), especially in Nadeau (2015), where it may be the most important indicator in a dry stream reach. An advantage of plants over other biological indicators of flow duration is that they are non-motile organisms, some of which have very long lifespans (i.e., decades). Therefore, they are well suited to reflect local, long-term conditions in a way that fish or invertebrates might not be. Thus, the taxonomic composition of plants found in the channel and immediate riparian zone may be an effective indicator of flow duration.

Several studies in the AW/WM show a very strong relationship between flow duration and plant communities (e.g., Caskey et al. 2015, Stromberg et al. 2007). Caskey et al. (2015) showed a decrease in wetland plant occurrence after diversion of perennial flow along stream reaches in the Routt National Forest, CO. Reynolds and Shafroth (2017) noted a number of plant species indicative of perennial versus intermittent flow regimes in high and low elevation streams in the Colorado Basin. Although that study did not identify ephemeral streams, the authors report that the driest streams in their study were dominated by upland plants, such as sagebrush and juniper (Lindsay Reynolds, personal communication).

One study in the NE (Ohio) explored herbaceous communities associated with floodplains (Goebel et al. 2002) and found four species indicative of riparian floodplains: false nettle (*Boehmeria cylindrica*), touch-me-not (*Impatiens capensis*), wood-nettle (*Laportea canadensis*), and white grass (*Leersia virginica*). All four are FACW throughout the NE/SE except for wood-nettle (FAC), though wood-nettle is FACW in the Atlantic and Gulf Coastal Plain. Another study in the SE (Mississippi; Choi et al. 2012) found potential indicator species of hydrologically influenced small headwater channel areas, including sweet white violet (*Viola blanda*), cylindricfruit primrose-willow (*Ludwigia glandulosa*), switch cane (*Arundinaria tecta*), and Christmas fern (*Polystichum acrostichoides*). All are FACW or OBL except for Christmas fern, which is FACU. Out of the four indicators, this species had the weakest association with headwater channels, but had a greater frequency of occurrence across the study area.

4.3.5 Vertebrates

Amphibians and Reptiles

Several SDAMs in and outside the NE/SE use vertebrates (fish, amphibians) as flow duration indicators, usually through measures of presence/ease of detection, abundance and/or diversity. NCDWQ (2010) indicates that certain species of frogs require very long larval stages (>1 year; includes *Rana*[1] *catesbeiana* [bullfrog], *R. heckscheri* [river frog], and *R. virgatipes* [carpenter frog]) and that presence of very large tadpoles of these species may indicate the presence of water over several seasons. To that end, NCDWQ uses the presence of large, multi-year tadpoles or larval salamanders (any species) to determine if a stream is perennial, even if the stream scores less than the perennial threshold. The presence of amphibian or snake life stages (adult, juvenile, larva, or eggs) identified as 'obligate' or 'facultative wet' in Nadeau (2015) indicate a stream is at least intermittent. Ohio EPA (2012) also uses amphibian (salamanders) indicator species for streams of different flow duration (Table 12), much like Nadeau (2015). The NE/SE region, and the southern Appalachian Mountains in particular, harbors a great diversity of salamander species. Some of these are largely terrestrial throughout their life cycle (e.g., *Plethodon* spp.), but others may be useful as flow duration indicators, including the widespread and common southern two-lined salamander (*Eurycea cirrigera*; Johnson et al. 2009). Table 12 presents studies in the NE/SE that explored the presence or identity of amphibians in conjunction with flow duration or drought conditions.

Partners in Amphibian and Reptile Conservation (PARC) has put out a series of Habitat Management Guidelines for the midwest (Kingsbury and Gibson 2012; includes IL, IN, MI, and OH), northeast (Mitchell et al. 2006), and southeast (Bailey et al. 2006). These guides identify those species that are most characteristic of certain aquatic habitats, including ephemeral/seasonal wetlands, small streams, and larger rivers for all or part of their life cycle (Table 11). As shown in the table, many species overlap habitats and would likely be considered semi-aquatic. For instance, studies of amphibians and reptiles in riparian corridors show that even those that require an aquatic environment for their life cycle often make extensive use of nearby terrestrial habitats (Connette et al. 2016, Guzy et al. 2019, Petranka and Smith 2005). However, there are exceptions—mudpuppies and waterdogs (*Necturus* spp.), as well as hellbenders (*Cryptobranchus alleganiensis*) are completely aquatic salamanders and do not generally live in habitats that readily dry. Two other aquatic salamander taxa, *Siren* spp. and *Amphiuma* spp. are also largely water dependent but can survive dry periods by aestivating in burrows in the substrate (Mitchell and Gibbons 2010).

[1] aka *Lithobates* (there is some dispute over the genus name for 'true' frogs; '*Rana*' will be used here)

Table 11. Characteristic reptile and amphibian species of different types of stream and wetland habitats in the midwest (Kingsbury and Gibson 2012), northeast (Mitchell et al. 2006) and southeast (Bailey et al. 2006).

Aquatic Habitat	Characteristic Species	Notes
Ephemeral/ seasonal wetlands (all regions; usually isolated)	**Salamanders**: blue-spotted (*Ambystoma laterale*), Jefferson (*A. jeffersonianum*), spotted (*A. maculatum*), small-mouthed (*A. texanum*), eastern tiger (*A. tigrinum*), marbled (*A. opacum*), mole (*A. talpoideum*), flatwoods (*A. cingulatum*), four-toed (*Hemidactylium scutatum*), and red-spotted newt (*Notophthalmus viridescens*). **Toads:** American (*Anaxyrus americanus*), Fowler's (*A. fowleri*), oak (*A. quercicus*), eastern narrow mouth (*Gastrophryne carolinensis*), eastern spadefoot (*Scaphiopus holbrookii*) **Frogs**: leopard (*Rana pipien* and *R. sphenocephalus*), wood (*R. sylvaticus*), gopher (*R. capito*), gray treefrog (*Hyla versicolor* and *H. chrysoscelis*), spring peeper (*Pseudacris crucifer*), ornate chorus (*P. ornata*), upland chorus (*P. feriarum*), southern cricket (*Acris gryllus*) **Turtles:** spotted (*Clemmys guttata*), blanding's (*Emydoidea blandingii*), eastern mud (*Kinosternon subrubrum*)	These wetlands harbor species that generally require water to reproduce but that also use nearby terrestrial habitats when wetlands dry. These species might also be encountered in or around fishless intermittent or ephemeral stream pools that hold water for long periods.
Small streams, springs, and seeps (Midwest)	**Salamanders**: four-toed, long-tailed (*Eurycea longicauda*), northern two-lined (*E. bislineata*), red-backed (*Plethodon cinereus*), red (*Pseudotriton ruber*), spring (*Gyrinophilus porphyriticus*), northern dusky (*Desmognathus fuscus*) **Frogs**: green (*R. clamitans*), pickerel (*R. palustris*) **Snakes**: queen (*Regina septemvittata*), northern watersnake (*Nerodia sipedon*)	Small headwater streams, often with intermittent flow and usually fishless; though springs and seeps are generally fed by groundwater, they are often isolated from other bodies of water by terrestrial habitats
Small streams, springs, and seeps (SE and NE)	**Salamanders**: dwarf waterdog^{+} (*Necturus punctatus*), spotted (*D. conanti*) and northern dusky, seal (*D. monticola*), seepage (*D. aeneus*), many-lined (*Stereochilus marginatus*), northern two-lined **Frogs**: green, pickerel, leopard, northern cricket (*A. crepitans*) **Snakes**: queen, northern watersnake, banded watersnake (*N. fasciata*) **Turtles**: loggerhead musk (*Sternotherus minor*), wood (*Glyptemys insculpta*) **Lizards**: coal skink (*Plestiodon anthracinus*)	Small headwater streams that are usually flowing but may be at a low volume; may or may not support predatory fish.

Aquatic Habitat	Characteristic Species	Notes
Rivers and large streams (all regions)	**Salamanders**: mudpuppy+ (*Necturus maculosus*), hellbender+ **Frogs**: bullfrog, river, northern cricket **Turtles**: alligator snapping (*Macrochelys temminckii*) and snapping (*Chelydra serpentina*), smooth (*Apalone mutica*) and spiny softshell (*A. spinifera*), map (*Graptemys* spp.), wood, river cooter (*Pseudemys concinna*), razor-backed (*Sternotherus carinatus*) and loggerhead musk **Snakes**: eastern ribbonsnake (*Thamnophis sauritus*), northern watersnake, diamond-backed watersnake (*N. rhombifer*), brown watersnake (*N. taxispilota*), queen, red-bellied mudsnake (*Farancia abacura*), rainbow (*F. erytrogramma*)	Generally perennial systems. The mudpuppy and hellbender are truly aquatic species that require water throughout their life cycle, while many of the turtles leave the water only to lay eggs.

+ Inidividuals of *Necturus* spp. (mudpuppies and waterdogs) and hellbenders are completely aquatic species of salamanders. *Necturus* retain external gills throughout their lives, while hellbenders retain gill slits but have working lungs as adults.

Table 12. NE/SE studies of amphibians and reptiles in different flow duration classes or ephemeral/seasonal wetland habitats.

Source	Region	Notes	Perennial	Intermittent/ Ephemeral/Drought Conditions
Buhlmann et al. (2009)	South Carolina (Aiken County)	Use of isolated, seasonal wetlands (Carolina Bays) and surrounding terrestrial habitats by turtles		When wetlands dried, chicken turtles (*Deirochelys reticularia*) would not retreat to a more permanent body of water, but would instead use terrestrial refugia
Erwin et al. (2016)	Okaloosa County FL (Gulf coastal plain)	Documented use of ephemeral wetlands by amphibians and reptiles		Characteristic species: dwarf salamander (*Eurycea quadridigitata*), reticulated flatwoods salamander (*Ambystoma bishopi*), southern cricket frog, southern leopard frog, eastern mud turtle, red-spotted newt, ornate chorus frog, southern toad (*Anaxyrus terrestris*). Others include cottonmouth (*Agkistrodon piscivorous*) and the glossy crayfish snake (*Regina rigida*)

Source	Region	Notes	Perennial	Intermittent/ Ephemeral/Drought Conditions
Johnson et al. (2009)	Kentucky, Indiana, Ohio (core sites); IL, NH, NY, VT, WV ('satellite' or validation sites)	Assessed ability of larval salamanders (largely southern two-lined, *Eurycea cirrigera*) and geomorphology measures to determine flow duration	Presence (expressed as CPUE) of *E. cirrigera*, combined with geomorphology measures was effective at delineating flow duration classes (perennial from intermittent/ephemeral) on a seasonal basis (spring vs. summer)	No larval salamanders were found at dry ephemeral sites
Lubbers (2009)	Hamilton County, Ohio (Cincinnati)	Compared amphibian communities in streams along a flow permanence gradient in urbanized settings.	*E. bislineata* larvae (northern two-lined salamander) abundance was greater in streams with higher permanence scores, but relationship was not significant	
Muncy et al. (2014)	Western piedmont of NC	Effects of drought on *E. cirrigera* in a semi-permanent stream		Terrestrial adults migrating to stream area (due to drought) increased capture probability, but monthly survivorship decreased (for adults)
Ohio EPA (2012)	Ohio	Salamander species that distinguish Class III (cold water perennial flow) from Class II (warm water, intermittent flow) streams	Associated taxa: *E. bislineata, E. cirrigera, E. longicauda, E. lucifuga, Gyrinophilus porphyriticus porphyriticus, G. p. duryi, Pseudotriton montanus diasticus*, and *P. ruber ruber*	Associated taxa: *Ambystoma* sp., *Desmognathus fuscus, D. ochrophaeus*, and *Hemidactylium scutatum*
Price et al. (2012)	Western piedmont of NC	Effects of drought on *D. fuscus* in a semi-permanent stream		Occupancy probability of adult northern dusky salamander did not change during drought conditions, but larval occupancy rates decreased suggesting mortality, failure of adult females to oviposit, or use of hyporheic zones

Source	Region	Notes	Perennial	Intermittent/ Ephemeral/Drought Conditions
Schneider (2010)	Southeast Kentucky	Characterized salamander communities of ephemeral streams		Species that require aquatic environments were found in ephemeral streams (e.g. seal and southern two-lined) though these species were often confined to the stream channel (i.e., not the stream banks) and were more associated with greater amounts of coarse woody debris. Species with the most captures include *Plethodon glutinosus* and *P. richmondi*, mostly on stream banks. Both species lack an aquatic larval stage.

Fish

Much like with certain amphibians, NCDWQ (2010) and Nadeau (2015) allow the presence of fish (except *Gambusia*, if only species present) to determine if a stream is perennial or at least intermittent, respectively. In the case of NCDWQ, the presence of fish can supersede a stream score less than the perennial threshold. Freshwater fishes also have high biodiversity in the SE, but time constraints for fish collection and identification in a rapid field-based SDAM make use of fish indicators of flow duration difficult, even though some limited work on this subject has been completed (see Davis 2017). Table 13 presents studies in the NE/SE that explored the presence or identity of fish in streams of different flow durations or seasonal wetlands.

Table 13. NE/SE studies of fish in different flow duration classes or ephemeral wetland habitats.

Source	Region	Notes	Perennial	Intermittent/ Ephemeral/Seasonal
Adams et al. 2018	North-central Mississippi	Assessed fish communities and crayfish occurrence in intermittent vs. perennial streams	*Fundulus olivaceus, Pimephales notatus*, *Lampetra aepyptera, Lepomis cyanellus, L. megalotus, Luxilis chrysocephalus*, and *Lythrurus umbratilis* were found to be significant indicators of perennial flow	No species were significant indicators for intermittent flow; the species with the highest indicator value was *Etheostoma parvipinne*.
Beugley and Pyron (2010)	East-central Indiana	Assessed fish community in 'seasonal' vs. perennial streams	The fish species in the seasonal reaches were a subset of those found in perennial reaches, generally at lower abundances (marginally significant). Species at perennial sites with much lower abundance at seasonal sites included *Rhinichthys obtusus* and *Semotilus atromaculatus*. Species found only in perennial reaches were *Campostoma anomalum* and *Micropterus salmoides*.	
Carlisle et al. (2010)	Nationwide	Analyzed changes in fish taxa among hydrologically altered streams, with focus on life history strategies	In hydrologically unaltered systems (year-round flow of sufficient magnitude), more taxa that are simple nesters and that dwell in benthic habitats are present	In systems with diminished minimum flow (perhaps leading to stream drying), more taxa that are nest guarders, active swimmers, and that prefer pool habitat are present
Christian and Adams 2014	Baxter and Stone Counties AR	Explored diet of fishes in a section of stream with 'connected' pools and 'isolated' pools	*Chrosomus erythrogaster*, *S. atromaculatus*, and *Etheostoma spectabile* were found in both connected and isolated pools	

Source	Region	Notes	Perennial	Intermittent/ Ephemeral/Seasonal
Davis (2017)	Southwest Georgia (Flint River basin)	Compared fish species assemblages in perennial and intermittent streams	23 indicator fish species (all age classes), though only 4 of these never found at intermittent sites: *Notropis longirostris, N. chalybaeus, Ichthyomyzon gagei*, and *E. parvipinne*	5 indicator species for intermittent flow: *Notropis* (aka *Pteronotropis*) *harperi, Centrarchus macropterus, Notemigonus crysoleucas, Elassoma zonatum,* and *Gambusia* sp.
Davis et al. (2020)	Southwest Georgia (Flint River basin)	Explored life-history traits that promote minnow survival in intermittent streams	NA (not applicable)	For minnow species most strongly associated with intermittent streams (*P. harperi*), the following life history traits were characteristic: reproductive timing outside typical stream drying, large reproductive investment, and smaller minimum length at maturity
Dekar and Magoulick (2013)	Northwest Arkansas	Studied effects of stream drying on predation patterns of fish and crayfish	NA	*C. anomalum* was common in the stream, and *Lepomis cyanellus* and *Micropterus punctulatus* were also observed.
Goss et al. (2012)	Southeast Florida	Studied fish movement into seasonally flooded wetlands of relatively short hydroperiod	NA	*Gambusia holbrooki* and *Jordanella floridae* actively colonize and escape ephemeral wetlands in response to flooding and drying.

5.0 PROPOSED INDICATORS

For the present study, we will evaluate indicators for the Pacific Northwest (Nadeau 2015) and North Carolina (NCDWQ 2010), including some additional indicators with positive evidence for determining flow duration in the primary literature, as well as any priority indicators from Table 5 not already included:

Geomorphological indicators

- Slope (Nadeau 2015)
- Continuity of channel bed and bank (NCDWQ 2010)
- Sinuosity of channel along thalweg (NCDWQ 2010)
- In-channel structure (NCDWQ 2010)

- Particle size of stream substrate (NCDWQ 2010)
- Active/relict floodplain (NCDWQ 2010)
- Depositional bars or benches (NCDWQ 2010)
- Recent alluvial deposits (NCDWQ 2010)
- Headcuts (NCDWQ 2010)
- Grade control (NCDWQ 2010)
- Natural valley (NCDWQ 2010)
- Second or greater order channel (NCDWQ 2010)
- Entrenchment ratio (Fritz et al. 2008; Johnson et al. 2009)
- Bankfull width and depth (Fritz et al. 2008; Johnson et al. 2009)
- Maximum pool depth (Fritz et al. 2008; Johnson et al. 2009)

Hydrologic indicators

- Presence of baseflow (NCDWQ 2010)
- Iron oxidizing bacteria (NCDWQ 2010)
- Leaf litter (NCDWQ 2010)
- Sediment on plants or debris (NCDWQ 2010)
- Organic debris lines or piles (NCDWQ 2010)
- Soil-based evidence of high-water table (NCDWQ 2010)
- Seeps and springs (NMED 2011)
- Number of woody jams within 10 m of the reach (Mersel and Lichvar 2014)

Biological indicators

<u>Aquatic macroinvertebrates</u>

- Presence of aquatic macroinvertebrates (Nadeau 2015; NCDWQ 2010). Early instars, partial terrestrial taxa, and aerially dispersing life stages will be noted separately, if encountered. Includes aquatic mollusks and crayfish.
- Abundance of mayflies (Nadeau 2015). Again, early instars will be ignored.
- Presence of perennial indicator taxa (Nadeau 2015, NCDWQ 2010). To facilitate this indicator, benthic macroinvertebrates will be identified to the following taxonomic levels:
    - Family: Aquatic Insects and Mollusks (with the exception of Corydalidae, which is identified to genus-groups following Cover et al. 2015)
    - Superorder or Order: Aquatic Mites and Crustaceans
    - Phylum or Class (if possible): Aquatic Annelida and others

  Every taxon that requires identification to the family level (i.e., aquatic insects and mollusks) will be collected for laboratory confirmation of field identifications. Additionally, whenever the identity of a specimen that requires family level ID is unknown or uncertain, vouchers will be collected to determine identification in the laboratory.

Algae and Bryophytes

- Algae (NCDWQ 2010)
- Presence of live or dead algal mats (Topping et al. 2009)
- Presence of streamer mosses (Topping et al. 2009)
- Presence of liverworts (Fritz et al. 2009, Vieira et al. 2016)
- Presence of pleurocarp and acrocarp bryophytes in the channel and banks (Fritz et al. 2009, Vieira et al. 2016).

Wetland and riparian plants

- Fibrous roots in streambed (NCDWQ 2010)
- Presence of wetland plants (includes FACW and OBL; NCDWQ 2010) Regional plant lists encompassing the NE/SE region shall be used (Lichvar et al. 2016).
- Rooted upland plants in streambed (NCDWQ 2010)

Vertebrates

- Presence of aquatic reptiles (Nadeau 2015) and aquatic stage amphibians (Nadeau 2015; NCDWQ 2010); identify to at least genus, if possible
- Presence of fish (NCDWQ 2011)

6.0 BIBLIOGRAPHY

6.1 Flow duration assessment methods

Here we present the sources reviewed for methodology or methodology validation in determining flow duration classes. Methods that were excluded based on the criteria in Figure 3 are presented separately; rationale for exclusion is provided in "*Notes*" for each entry. Where applicable, validation studies or studies associated with the development of a method are listed under "*Related Sources*".

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APPENDIX A:

LITERATURE SCREENING FOR POTENTIAL FLOW DURATION TESTING SITES

This appendix catalogs screening results of literature reviewed for potential leads on baseline or validation sampling sites, with particular focus on intermittent and ephemeral sites. Screening questions included: 1) flow duration classes identified and how/if they were defined; 2) how/if flow duration classes were determined; 3) year(s) work conducted; and 4) locality information provided by the author(s). Reviewed literature was the result of new searches and that already identified during the original review. New searches done for this purpose are presented in Table A-1.

Table A-1. Literature searches to support baseline/validation site identification.

Search Source	Search Date	Key Terms	Hits
Web of Science (WOS)	7/9/2020	("northeastern United States" OR “southeastern United States” OR “Appalachian” OR “New England”) AND (“intermittent” OR “ephemeral” OR “wet weather conveyance” OR “stormflow channel” OR “temporary flow” OR “seasonal flow”) AND ("gauge" OR "logger" OR "weir" OR "flume")	4
WOS	7/9/2020	("Maine" OR "New Hampshire" OR "Massachusetts" OR "Vermont" OR "New York" OR "Connecticut" OR "Rhode Island" OR "New Jersey" OR "Pennsylvania" OR "Delaware" OR "Maryland" OR "Virginia" OR "West Virginia" OR "Ohio") AND (“intermittent” OR “ephemeral” OR “wet weather conveyance” OR “stormflow channel” OR “temporary flow” OR “seasonal flow”) AND ("gauge" OR "logger" OR "weir" OR "flume")	29
WOS	7/9/2020	("North Carolina" OR "South Carolina" OR "Georgia" OR "Florida" OR "Alabama" OR "Mississippi" OR "Texas" OR "Arkansas" OR "Tennessee" OR "Oklahoma" OR "Missouri" OR "Illinois" OR "Indiana" OR “Michigan”) AND (“intermittent” OR “ephemeral” OR “wet weather conveyance” OR “stormflow channel” OR “temporary flow” OR “seasonal flow”) AND ("gauge" OR "logger" OR "weir" OR "flume")	47
WOS	7/9/2020	("northeastern United States" OR “southeastern United States” OR “Appalachian” OR “New England” OR “northeast” OR “southeast”) AND “hydrological connectivity” AND “stream”	13
WOS	7/9/2020	("Maine" OR "New Hampshire" OR "Massachusetts" OR "Vermont" OR "New York" OR "Connecticut" OR "Rhode Island" OR "New Jersey" OR "Pennsylvania" OR "Delaware" OR "Maryland" OR "Virginia" OR "West Virginia" OR "Ohio") AND “hydrological connectivity” AND “stream”	12

WOS	7/9/2020	("North Carolina" OR "South Carolina" OR "Georgia" OR "Florida" OR "Alabama" OR "Mississippi" OR "Texas" OR "Arkansas" OR "Tennessee" OR "Oklahoma" OR "Missouri" OR "Illinois" OR "Indiana" OR "Michigan") AND "hydrological connectivity" AND "stream"	27
Google Scholar	7/29/2020	("Maine" OR "New Hampshire" OR "Massachusetts" OR "Vermont" OR "New York" OR "Connecticut" OR "Rhode Island" OR "New Jersey" OR "Pennsylvania" OR "Delaware" OR "Maryland" OR "Virginia" OR "West Virginia" OR "Ohio") AND "headwater" AND "intermittent stream"	13,800
Google Scholar	7/29/2020	("North Carolina" OR "South Carolina" OR "Georgia" OR "Florida" OR "Alabama" OR "Mississippi" OR "Texas" OR "Arkansas" OR "Tennessee" OR "Oklahoma" OR "Missouri" OR "Illinois" OR "Indiana" OR "Michigan") AND "headwater" AND "intermittent stream"	12,300

In some cases, a study used a 'standard' definition of perennial, intermittent, and ephemeral streamflow duration. In this context, the standard definition generally follows that given by NCDWQ (2010; Table A-2).

Table A-2. Streamflow Duration Standard Definitions

Flow Duration	NCDWQ (2010) Definition
Perennial	A well-defined channel that contains water year-round during a year of normal rainfall with the aquatic bed located below the water table for most of the year. Groundwater is the primary source of water.
Intermittent	A well-defined channel that contains water for only part of the year, typically during winter and spring when the aquatic bed is below the water table. Flow may be heavily supplemented with stormwater runoff.
Ephemeral	A feature that carries only stormwater in direct response to precipitation with water flowing only during and shortly after large precipitation events. The aquatic bed is always above the water table and stormwater runoff is the primary source of water.

Table A-3 contains the screening information for literature with potential to provide baseline or validation sites. **NOTE**: Indicator and method references are found in Section 6.0; all others (starred) are at the end of this Appendix.

Table A-3. Literature Screening for Potential NE/SE Baseline and Validation Sampling Site Selection. Note: Indicator and method references are found in Section 6.0; all others (starred) are at the end of this Appendix.

Source	Flow Classes and Definition (where available)	How is Flow Class Determined?	Year Work Conducted	Provided Locality Information
Adams et al. 2018	Ephemeral, intermittent, perennial; intermittent if flume was dry >10 consecutive days, ephemeral reaches flowed intermittently and lacked a well-defined stream channel	Flumes (on some reaches) and observations in the dry season; differences in fish community (see Table 13)	2011-2013	Coordinates (including info on how flow duration was determined) and map; Calhoun County MS
Beugley and Pyron (2010)	Perennial (maintain surface flow during non-drought years) and seasonal (dry in late summer to early fall in most years)	Weekly observations in summer	2007	Site map but no coordinates; east-central Indiana (Buck Creek watershed)
Brahana and Hollyday 1988*	No classes given; streams in karst terrain with 'dry' reaches downstream of 'wet' reaches. The case study dry reach had no flow for 60% of the year.	Whether stream has a dry reach is determined from aerial photos and field observation for characteristic channel features and presence of flow.	1977	Map of wet and dry reaches on case study stream (Union Hollow Branch), relative to its mouth at Norris Creek; south-central TN
Brown et al. 1997*	Intermittent; continuous surface flow only 5-10 days a year but generally have isolated spring pools throughout that never dry completely	Unknown, likely observation	Unknown	No map or coordinates; Ouachita NF
Brozka et al. 1981*	Intermittent, defined as 'flow occurring only when there is precipitation and soil is sufficiently charged w/moisture'	V-notch weir and water level recorder monitored for 3 years. Flows were over several weeks or as short as a few hours	1976-1978	No map or coordinates. Watersheds are in Shawnee NF, at the Dixon Springs Ag Center in Pope County, IL
Burke et al. 2014*	Ephemeral, intermittent, perennial; standard definitions	Unknown	2008-2009	Maps only; Buckhorn Creek watershed, Breathitt County, KY
Chadwick and Huryn 2003*	No classes given; however, 'streams dry during summer'	Weirs, temperature loggers	1997-1999	Site coordinates are given; Hancock County, ME

Source	Flow Classes and Definition (where available)	How is Flow Class Determined?	Year Work Conducted	Provided Locality Information
Chadwick and Huryn 2005*	Intermittent; no definition given	Weirs, temperature loggers	1999-2000	Latitude is given, appears to be same streams as in Chadwick and Huryn 2003, based on site IDs
Chadwick and Huryn 2007*	Intermittent; no surface water from June (or earlier) until autumn	Monthly observations, weirs	1998-1999	General reach map, but no coordinates; Bear Brook watershed, ME
Chadwick et al. 2012	Intermittent, perennial; intermittent streams lacked water for several weeks in autumn and spring or intermittently lacked flow	Monthly discharge calculated from total wetted-width, current velocities, and water depth at 0.25 m intervals.	2003-2004	Map, but no coordinates; tributaries of the St. Johns River in Northeast Florida (Jacksonville)
Choi et al. 2012	Ephemeral, intermittent; in summer and drought years, intermittent streams flow only in response to precipitation	Ground water wells and observations of defined channel development	2007-2009	No map or coordinates; Webster County, MS
Christian and Adams 2014	Intermittent section of stream with isolated pools, connected only after heavy rainfall; downstream of perennial, connected section	Unknown	2011	Detailed map, general site coordinates; North Sylamore Creek drainage, Baxter and Stone Counties, AR
Courtwright and May 2013	Intermittent; does not flow continuously, study reaches had isolated pools only	Historically known	2011	Map, but no coordinates; Dry River catchment in GW National Forest, VA
Davis et al. 2003	Intermittent; flow was intermittent May-December	Stream flow velocity measured with an electric current meter; monthly mean watershed discharge data	1998-1999	Map, but no coordinates; Piscola Creek watershed in the Suwannee River basin, southwest GA

Source	Flow Classes and Definition (where available)	How is Flow Class Determined?	Year Work Conducted	Provided Locality Information
Davis 2017	Intermittent; no definitions given aside from streams have 'dry periods'	Periods of pool isolation, drying, and resumption of flow were assessed using a combination of USGS gage data, visual monitoring, and diel changes in temperature	2015-2017	Watershed level map but no coordinates; Flint River basin, southwest GA
Davis et al. 2020	See Davis 2017			
DeJong and Canton 2013	Intermittent and ephemeral; ephemeral sites at upstream terminus of flowing water, while intermittent sites were downstream where wetted width equaled 0.3 m	Observations of geomorphic (e.g., channel formation), hydrologic (e.g. springs), and biologic indicators (e.g. vegetation)	2010	Map, but no coordinates; southwest WV, three different protected natural areas
Dekar et al. 2009*, Dekar and Magoulick 2013	Intermittent; periodically intermittent flow with dry riffles and isolated or dry pools	Observation and discharge data from a USGS gaging station downstream (07252000)	2006-2007	Coordinates (Dekar et al. 2009) and map; Boston Mtns, northwest AR
Delucchi 1988	Permanent (flows all year), intermediate (flows for >9 mos.), dry (flows for <9mos.)	Unknown; stream discharge measured during site sampling	1982	Map, but no coordinates; Tompkins Co. NY (Ellis Hollow, Hunt Hill Creek)
DiStefano et al. 2009	Intermittent; no definition given, aside from the observation that both riffles and pools dried completely during late summer	Observations, measurements of wetted width/area and stream discharge	2005-2007	No map or coordinates; southwest MO (Mark Twain NF)
Eaton and Vander Vorste 2012	Ephemeral, intermittent, perennial; standard definitions	Use of NCDWQ method, with limited observations	2009-2011	Map, but no coordinates; however, have received coordinates and associated site flow duration from R. Vander Vorste (AL, FL, GA, KY, MS, SC, TN)

Source	Flow Classes and Definition (where available)	How is Flow Class Determined?	Year Work Conducted	Provided Locality Information
Epting et al. 2012*	Temporary streams connecting 'isolated' wetlands to perennial stream network. Temporary streams generally had flow <9 mos. out of the year	Flow switch state data loggers	2015	General vicinity map, but no coordinates; Choptank and Corsica River watersheds in MD
Febria et al. 2015	Permanent and temporary; no definitions given aside from the temporary streams experienced seasonal drying	Unknown	2012	Coordinates and general vicinity map; Parkers Creek MD
Feminella 1996	Perennial, intermittent (range of permanence); no definitions given, but streams termed intermittent ceased flowing during normal summer conditions	Combination of median discharge, minimum discharge at summer baseflow and mean wetted area of riffle at summer baseflow	1994-1995	No map or coordinates; Talladega NF, AL
Flinders and Magoulick 2003	Permanent, intermittent; no definitions given	Observations	1998	Map, but no coordinates; Ozark Plateau, northern AR and southern MO
Fritz et al. 2006*	Intermittent; streams flowed for <6mos.	Unknown	1998-1999	General lat/long of study area, no map; lower Alabama River watershed, Monroe County, AL
Fritz et al. 2010	Ephemeral, intermittent, and perennial; standard definitions	Electrical resistance loggers	2006	No map or coordinates; Buckhorn Creek catchment, Breathitt County KY

Source	Flow Classes and Definition (where available)	How is Flow Class Determined?	Year Work Conducted	Provided Locality Information
Fritz et al. 2013	Perennial reaches had no dry periods; intermittent reaches had dry periods and a max period of flow >29 days; ephemeral reaches had a max period of flow equal to or less than 29 days. For sites with observations only, perennial channels had water in both wet and dry season, intermittent channels had water only in the wet season, and ephemeral channels were dry in both.	NC DWQ method; 32 of 51 sites had loggers (30 operational) deployed for 1 year, others relied on two observations (one during the 'wet' and 'dry' season)	2010-2011	Large scale map without coordinates; South Carolina (Piedmont and SE Plains Level III ecoregions)
Fritz et al. 2019	Ephemeral; standard definition	Electrical resistance loggers	2013-2014	Map, only general site coordinates; Clemons Fork drainage of Univ of Kentucky Robinson Forest
Genereux et al. 1993*	Perennial; no definition given	V-notch weir with automatic stream stage recording at 5-minute intervals.	1989-1990	No map or coordinates; West Fork of Walker Branch watershed, Oak Ridge TN
Goebel et al. 2002	Intermittent; no definition given	Unknown	2001	Very general map, no coordinates; Johnston Woods State Nature Preserve, OH
Governo et al. 2004*	Intermittent; no definition given	Mean annual discharge is given, but method of determination not discussed	1998-2000	General lat/long of study area, map; Monroe County AL (streams flow to Big Flat Creek)
Grubbs 2011	Perennial and temporary; definitions as in Svec 2003	Svec 2003	2004-2005	Map, but no coordinates; Clemons Fork drainage of Univ of Kentucky Robinson Forest

Source	Flow Classes and Definition (where available)	How is Flow Class Determined?	Year Work Conducted	Provided Locality Information
Hosen et al. 2017*	Perennial streams, wetland 'temporary connections'; temporary channels were dry in summer when evapotranspiration was high (June-October)	Observation of temporary channel connection	2010-2012	No coordinates, general vicinity map; Tuckahoe Creek watershed in the Delmarva Peninsula
Howard 2007	See Williams 2005			
Inamdar et al. 2011*	Perennial and less than perennial (the term intermittent is not used)—the less than perennial stream 'occasionally dries up and is hydrologically disconnected during driest parts of the year' (Aug-Oct)	Observation, groundwater wells along or near tributaries, outlet of system monitored using a Parshall flume	2008-2010	General study area coordinates and map; Fair Hill Natural Resources Mgmt Area, Cecil County MD (streams flow to Big Elk Creek)
Johnson et al. 2009	Perennial (at least interstitial flow through summer), intermittent (flow during spring; dry or pools only in summer), ephemeral (dry on both sampling visits)	Observations in spring (wet) and summer (dry)	2003-2004	No map or coordinates; sites in IN, KY, and OH
Kelso 2012	Perennial (all year flow, even if extremely low flow) and intermittent (201-315 days of flow, with or without isolated pools)	Camera monitored gages (intermittent), USGS gages (perennial)	2010-2011	Site map, but no coordinates; South Fork Little Red River and Point Remove drainages in north-central AR
Kelso and Entrenkin 2018	Intermittent and perennial; intermittent reaches broken into 7 and 9 months of 'connected' flow duration	Flow duration curves using USGS gage data, camera monitored gages at intermittent sites (deployed 1 year)	2010-2011	General map, but no coordinates; Gulf Mtn Wildlife Mgmt Area, AR
Kilbane and Holomuzki 2004*	Intermittent; stream dries from early summer to late autumn	Unknown, but likely observation	2001-2002	Coordinates given, no map; north-central OH
Lampo 2014	Perennial, intermittent, ephemeral; uses definitions in Fritz et al. 2013	Direct measurement (water sensors), twice a month observations, NCDWQ method	2013	Detailed site maps w/aerials but no coordinates; southern IL (Jackson County)

Source	Flow Classes and Definition (where available)	How is Flow Class Determined?	Year Work Conducted	Provided Locality Information
Lubbers 2009	Subset of streams from Roy et al. 2009			
Maigret et al. 2014*	Ephemeral; flow only during short periods of surface runoff events	Unknown, but flow durations seemed to be well known in study watershed	2007-2008	No coordinates or map; Clemons Fork drainage of Univ of Kentucky Robinson Forest
Miller et al. 1988*	Ephemeral grading to intermittent; no definitions given	Unknown	1979-1983	No coordinates, very general map; Ouachita Mtns approx. 35 miles north of Little Rock AR
Mulholland 1993*	Ephemeral and perennial; ephemeral streams flow for periods of less than one week following rain events	Flumes on ephemeral and perennial streams, as well as shallow wells	1991	General study area coordinates and map; West Fork of Walker Branch watershed, Oak Ridge TN
Neary et al. 1986*, Nutter et al. 1984*	Ephemeral; all flow occurred as stormflow (standard definition)	H-flumes, analog water level recorders	1979-1981	Map, but no coordinates; Chattahoochee NF in NE GA, Moonshine Creek drainage
NC Division of Water Quality 2005	Ephemeral, intermittent, perennial; standard definitions	NCDWQ method, or combination of wells and method; 8 streams had wells installed and monitored (Schenk, Ums, and Fall; all Raleigh area), for 18 mos. (see Williams 2005 for hydrographs)	2002, 2004	Coordinates and stream scores are given; NC piedmont and mountains
NCDWQ 2010*	Ephemeral, intermittent, perennial; standard definitions	NCDWQ method and monthly observations of flow/water presence; it should be noted that the authors observe that NCDWQ flow duration score thresholds may not be as applicable in the sandhills region	2007-2008	Coordinates and general site map; NC coastal plain and sandhills

Source	Flow Classes and Definition (where available)	How is Flow Class Determined?	Year Work Conducted	Provided Locality Information
Roy et al. 2009	Ephemeral, intermittent, perennial; perennial flowed in spring and summer, intermittent flowed only in spring, and ephemeral did not flow in spring or summer	Observations in spring and summer; flow permanence designations compared to a larger dataset (5 years of observations compared to 1)	2006	Map, but no coordinates; Hamilton County OH
Salant et al. 2007*	Ephemeral; contribute water during large storm events and spring high flows only	Unknown, but likely observation	2004	Detailed map, but no coordinates; eastern VT
Santos and Stevenson 2011	Perennial (constant flow), intermittent (up to 4 mos. no flow), ephemeral (4 or more mos. of no flow)	Weekly observations during summer for 3 years prior to the study, coupled with normal precipitation levels for the region	2001-2005	Detailed site map, but no coordinates; Boxford MA
Schneider 2010	Ephemeral; limited to no water flow throughout the year	Water level data from another researcher (C. Barton, Univ of KY)	2007-2008	Detailed site map, reach lengths and elevations, but no coordinates; Clemons Fork drainage of Univ of Kentucky Robinson Forest
Secoges et al. 2013*	Intermittent transitioning to perennial; no definitions given	Unknown	2007-2008	Map, but no coordinates; Buckingham County, VA
Smith et al. 2017	Perennial, near-perennial (ceased flowing but maintained wetted channel during drought), intermittent-dry (seasonally dry), and intermittent-frequent (frequently dry)	Available hydrologic records and observations during a years-long drought	2013	Map, but no coordinates; lower Flint River basin, southwest GA
Smock et al. 1989*	Perennial (permanent flow) and intermittent (channel dries completely or only has isolated pools in summer and fall)	Discharge measurements (perennial), 5 years of observations (intermittent)	1984-1985	No map or coordinates; Surry County VA, Colliers Creek (intermittent), Buzzards Branch (perennial)

Source	Flow Classes and Definition (where available)	How is Flow Class Determined?	Year Work Conducted	Provided Locality Information
Viosca 2007*	Perennial (continual flow in spring and summer), intermittent (continual flow in spring, intermittent flow in late summer); 2 sites with intermittent flow in spring but that dried completely were not classified	Observations of mean wetted width in spring and late summer	2006	Coordinates and map; Winn Parish, central LA
Williams et al. 2003	Intermittent; stream dries to isolated pools by summer	Observation		Site coordinates, no map; Alum Creek, Ouachita Mtns, southwest AR
Williams 2005	See NCDWQ 2005			
Witt et al. 2013*	Ephemeral; water table is below channel bed and groundwater not significant source of water	Pressure transducers measuring stream stage	2008-2010	Map, but only general study area coordinates; Univ of Kentucky Robinson Forest (SE KY)
Yarra and Magoulick 2018	Permanent (never experience complete drying) and intermittent (substantial flow variability, including complete drying in late summer)	Drainage area size, hydrologic regime models developed by Leasure et al. (2016)	2014-2015	Map, but no coordinates; Ozark-Ouachita Highlands in AR and MO
Zimmer et al. 2012*	Ephemeral, intermittent, perennial; uses definitions from Hansen (2001)	Ephemeral channels delineated in the field as locations with first signs of flow (displacement of leaves and organic matter). Transitions to other flow types were made using repeated field surveys over a range of flow conditions	2009-2010	Detailed site map, but no coordinates; watershed 3 at Hubbard Brook Experimental Forest, NH

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