Review of Flow Duration Methods and Indicators of Flow Duration in the Scientific Literature: Alaska

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1.0 STATEMENT OF PURPOSE

The purpose of this review is to document methods and indicators that may be used to develop a streamflow duration assessment method (SDAM) for the state of Alaska, with an emphasis on field-based indicators and methods that distinguish ephemeral, perennial, and intermittent streams. It describes indicators proposed for testing at both baseline and validation sites across the state, 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 Alaska, where possible. Literature screened for the purpose of identifying possible study sites 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 gages) 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 gages 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).

Alaska has a great range of annual precipitation that varies significantly by latitude (Figure 1). The south coast of Alaska, between the southeast coastal range (Juneau area) and the Aleutian island chain, has a mean annual precipitation that ranges from approximately 24 inches to almost 300 inches. Mean annual precipitation ranges from approximately 14 to 24 inches in the Alaskan interior, whereas north of the Brooks Range (also known as the ‘North Slope’) it can be less than 10 inches, though totals closer to 15 inches are more typical. Differences in precipitation and temperature across Alaska have also resulted in a great diversity of vegetation and ecoregion types (Figure 3). The south coast (minus the Aleutians) is characterized by dense coniferous forest; in the southeast part of the state this forest is an extension of the temperate rainforest that extends northward along the west coast from northern California. Interior

Alaska is generally characterized by boreal forest dominated by white and black spruce, while the north and west coast is primarily tundra vegetation, with few to no trees.

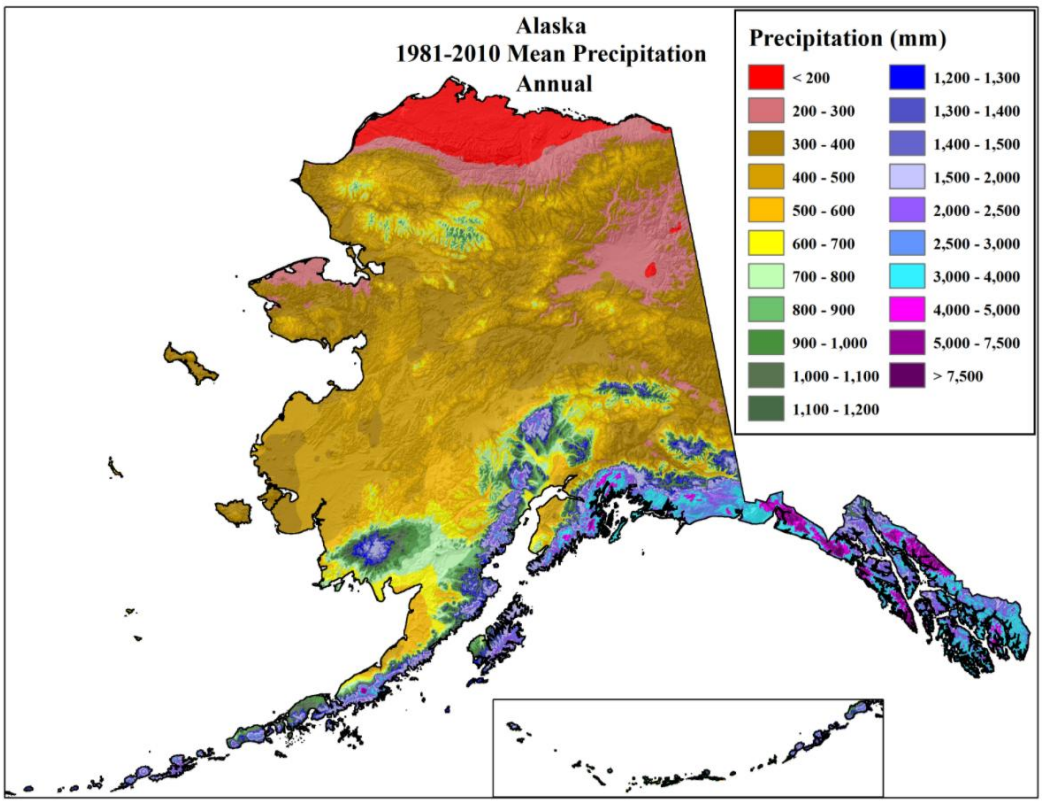


Figure 1. Annual mean precipitation for Alaska, 1981-2010 (PRISM Climate Group, Oregon State University, map created 2018; http://prism.oregonstate.edu)

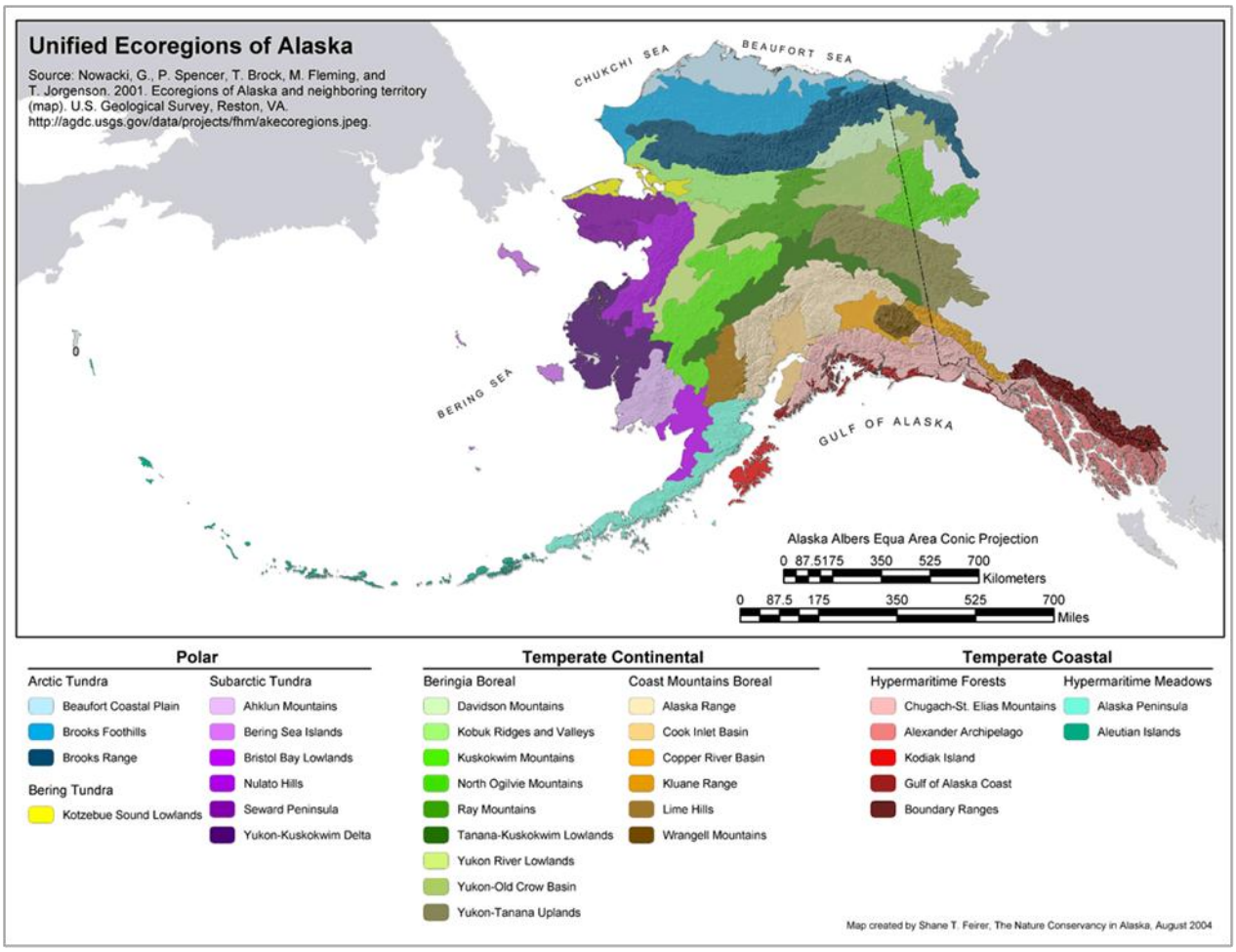


Figure 2. Unified Ecoregions of Alaska (Nowacki et al. 2001; map created by The Nature Conservancy, 2004).

Alaska is also distinct from the rest of the U.S. in having permafrost, which is soil, rock, or sediment that is frozen for more than 2 consecutive years. Permafrost in Alaska is overlain by a layer of soil that thaws each year called the active layer. Figure 3 shows the distribution of permafrost across Alaska; the distribution of permafrost categories (e.g., continuous, discontinuous, sporadic) characterizes the percent of the land area that is underlain by permafrost in the upper 10 meters of the soil profile. The presence of permafrost is important for the region's water budget because permafrost controls infiltration capacity. Precipitation and runoff from snowmelt are confined to the active layer, which can range from a few millimeters to more than a meter thick. Consequently, even areas with low precipitation such as the North Slope support abundant wetlands and saturated soil. For example, Hall et al. (1994) found that in the Arctic foothills and coastal plain (equivalent to the Brooks foothills and Beaufort coastal plain in Figure 2), wetlands comprise approximately 83% of the total land area.

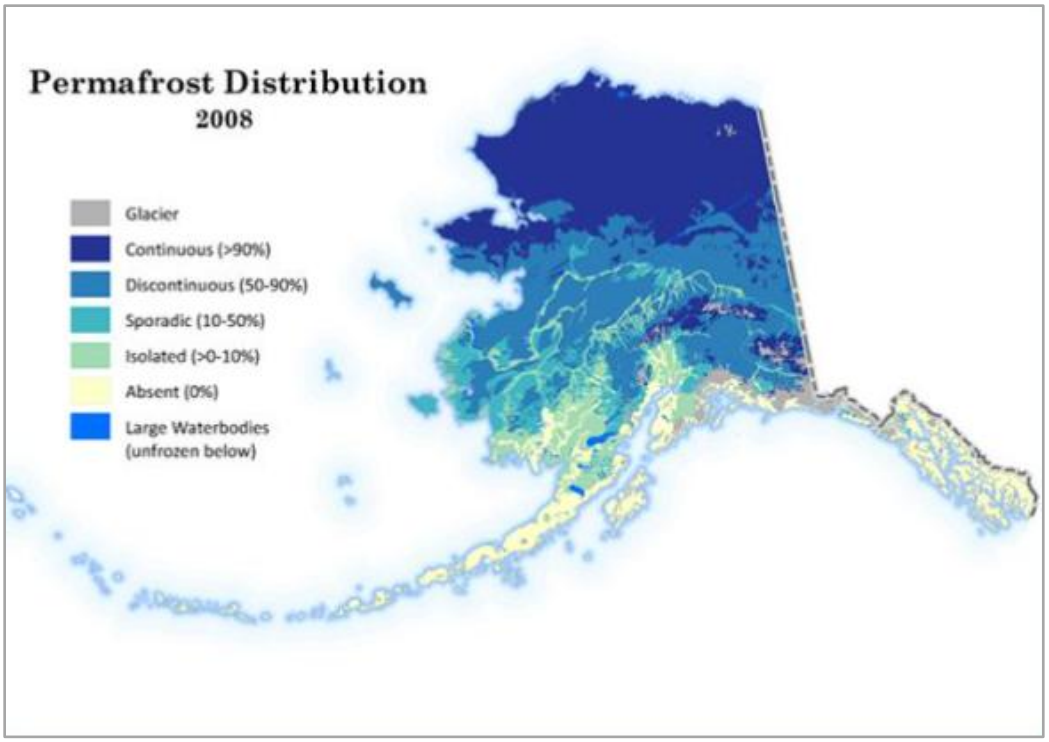


Figure 3. Permafrost distribution (% area with permafrost within upper 10m of soil profile) in Alaska (adapted from Jorgenson et al. 2008).

The North Slope also has a significant number of streams that freeze solid and into the sub-surface during winter. Huryn and Hobbie (2012) observe that the water column generally freezes solid in North Slope streams that are <2 meters deep and not spring-fed; however, there may be exceptions to this rule, especially in 'beaded' streams (Arp et al. 2015). Beaded streams have regularly spaced, ovoid pools that are connected by narrow runs where perennial liquid water occurs in most deep pools. In their literature review, Tolonen et al. (2019) observed that there may be a similar biological community response to intermittent and ephemeral streams (IRES) and streams that freeze solid in the winter (FIRES; Figure 4). While FIRES may not be considered 'intermittent' for all definitions of intermittent flow duration, the lack of free surface water during winter in these systems may have lessons for determining biological field indicators of streamflow duration.

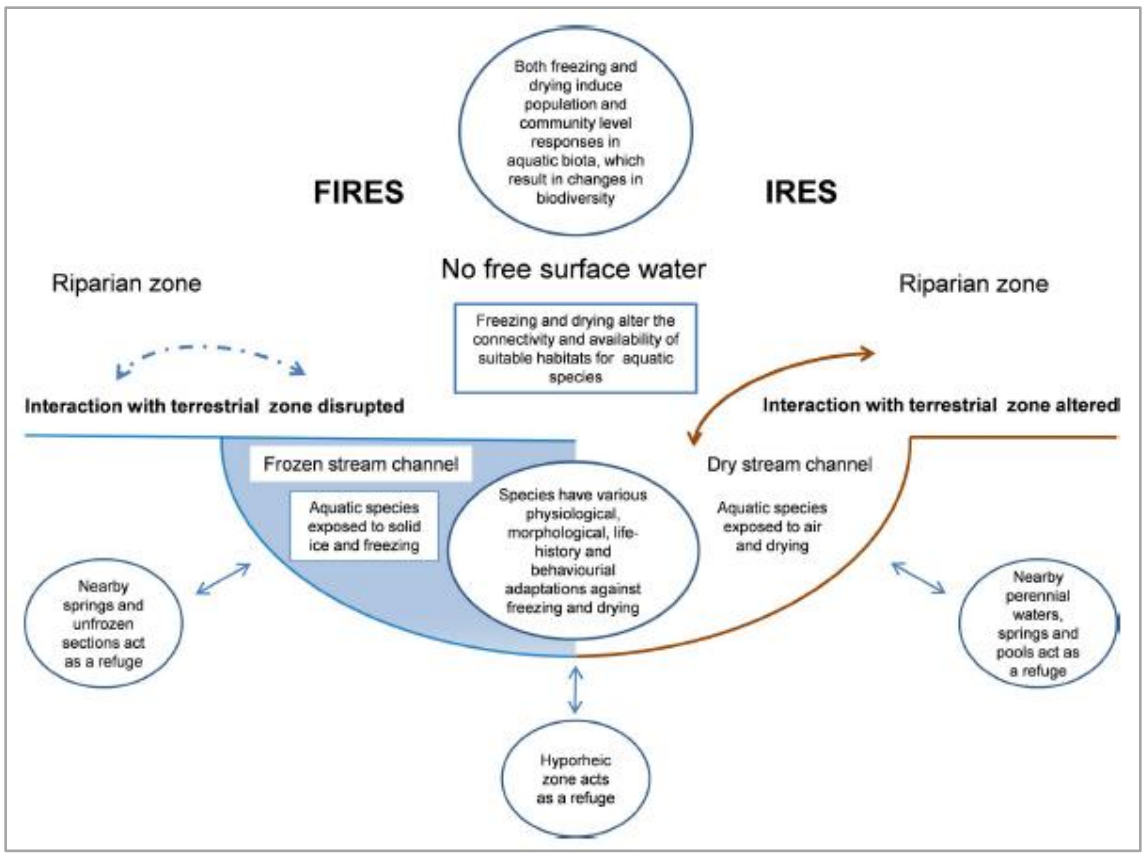


Figure 4. Similarities of Biological Response to Intermittent Rivers and Ephemeral Streams (IRES) and Freezing IRES (FIRES; from Tolonen et al. 2019).

2.0 METHODS

2.1 General approach

Literature reviews have been completed to support the development of regional SDAMs for nationwide coverage by the agencies: the Arid West (AW; McCune and Mazor 2019), the Western Mountains (WM; McCune and Mazor 2020), the Great Plains (GP; James et al. 2020a), the Northeast and Southeast (NE/SE; James et al. 2020b), U.S. Caribbean (Garcia-Rosado et al. 2026), and Hawaii (HI, James et al 2026). For the current literature review, existing flow duration assessment methods, regional references (e.g., primary literature, government reports), and indicators identified in previous literature reviews were reevaluated for their applicability to Alaska. In addition, further queries of literature databases were conducted to identify and evaluate additional regionally specific flow duration methods, references, and indicators that should be considered. Flow duration assessment methods evaluated for this analysis are generally limited to those with rapid field-based measurements and are not heavily dependent on modeling or gage data.



Figure 5 Map of study regions included in the development of SDAMs for use across the U.S.

As with the other regions, candidate field indicators of flow duration for Alaska were identified from established flow duration methods (Figure 6). Indicators were categorized by type (geomorphology, hydrology, or biology) and metric used to assess the indicator (e.g., presence of perennial macroinvertebrate indicator taxa, baseflow, or depositional features). This initial set was supplemented with additional indicators whose use was supported by the scientific literature but were not incorporated into established methods. The full list of potential indicators was then evaluated for five key criteria:

> *Consistency*: Does it work? Is there evidence from appropriate references (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 (as a control or a response) 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 or conditions too harsh, an indicator may be inappropriate for further investigation.

Based on these criteria, a final list of possible indicators of flow duration were selected as candidate indicators that can be evaluated in an SDAM development study for Alaska. A subsequent objective is to determine how well the Pacific Northwest and Oregon interim SDAMs (Nadeau 2015; Topping et al. 2009) reflect the known flow duration of Alaska sample sites as both of these: 1) apply to regions with some hydrologic landscapes similar to those found in Alaska and; 2) provide a definitive flow duration class as an output, using either a decision tree or a score.

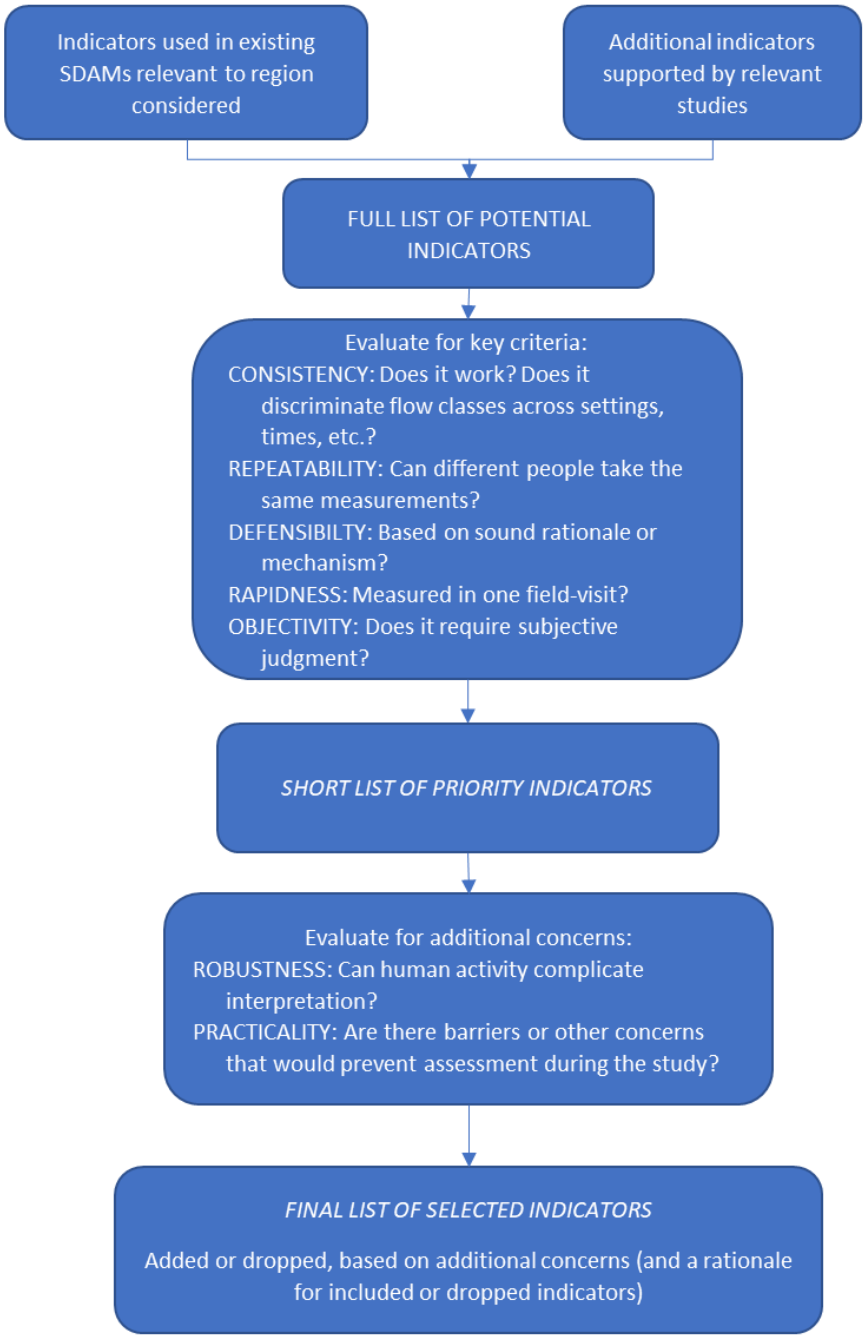


Figure 6. Process for identifying indicators of flow duration.

2.2 Search methods

First, literature identified in the previous reviews were evaluated for their relevance to Alaska. These included flow duration methods from across the U.S. and elsewhere, references that could be more broadly applied across regions, and literature with data specific to Alaska. These references have already been evaluated using the decision tree shown in Figure 7 for the

previous literature reviews. Therefore, no further analysis was performed on these references, unless they had information specific to Alaska.

To compile a more thorough collection of Alaska-specific or relevant flow duration references, additional searches using 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 100 search results were reviewed to determine applicability to subject and Alaska. This compiled library was also supplemented by appropriate sources from the personal libraries of the technical team, and input from members of the Alaska Regional Steering Committee.

Table 1. Search engines (WOS = Web of Science, GS = Google Scholar, Google = Google), dates, terms, and hits used to assemble literature on indicators of flow duration in Alaska.

Search Source	Search Date	Search Terms and Combinations	Hits
WOS	12/4/20	"Alaska" 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")	12
WOS	12/4/20	"Permafrost" 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	12/4/20	"Alaska" AND ("macroinvertebrates" OR "amphibians") AND "stream"	67
WOS	12/7/20	“Arctic” AND “stream” AND (“perennial” OR “intermittent” OR “ephemeral”)	42
GS	12/15/20	“Temperate Rainforest” AND “stream” AND (“perennial” OR “intermittent” OR “ephemeral”)	1,480
GS	12/15/20	“Yukon” AND “stream” AND (“perennial” OR “intermittent” OR “ephemeral”)	9,520
GS	12/4/20	"Alaska" AND “flow duration”	1,270
GS	12/4/20	“Alaska” AND “stream” AND (“perennial” OR “intermittent” OR “ephemeral”)	53,100
GS	12/4/20	"Alaska" AND "flow duration" AND ("macrophytes" OR "algae" OR "bryophytes" OR “riparian vegetation”)	437
GS	12/7/20	"Alaska" AND "flow duration" AND ("macroinvertebrates" OR "fish" OR "amphibians")	687
Google	12/15/20	“Alaska” AND “flow duration”	20,900
Google	12/7/20	“Alaska” AND “streamflow duration” AND “indicator”	1,090
GS	12/7/20	“Alaska” AND “hydrological connectivity” AND “stream”	902
GS	12/7/20	“Alaska” AND “headwater” AND “intermittent stream”	520

2.3 Analysis of sources

2.3.1 Evaluating References in the Review

Applicability/Utility: Identified references were first reviewed to determine if a reference was 'applicable' for this analysis. Applicable sources were those that provided information about the biological, physical (i.e., geomorphological), or hydrologic characteristics of streams along a flow duration gradient in Alaska. References in regions outside of Alaska were also considered applicable if other elements of the reference were relevant to the study. For instance, references from other areas of temperate rainforest or climatologically similar areas of Canada, or those that dealt with aquatic macroinvertebrate families/genera also found in Alaska. Common factors that limited the applicability of a citation include reliance on intensive hydrologic data (e.g., continuous flow gage 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 reference was considered applicable, it was evaluated for inclusion in this review following the decision tree in Figure 7 and as described below.

Review: References needed to undergo peer-review, be published by a government agency, or come from a subject-matter expert.

Soundness: References needed to rely on sound scientific principles, and conclusions had to be consistent with data presented.

Clarity/Completeness: References needed to provide underlying data, assumptions, or model parameters, as well as author sponsorship or author affiliations. Several references 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 reference was excluded from the review.

Uncertainty/Variability: References needed to identify variability, uncertainties, references 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.

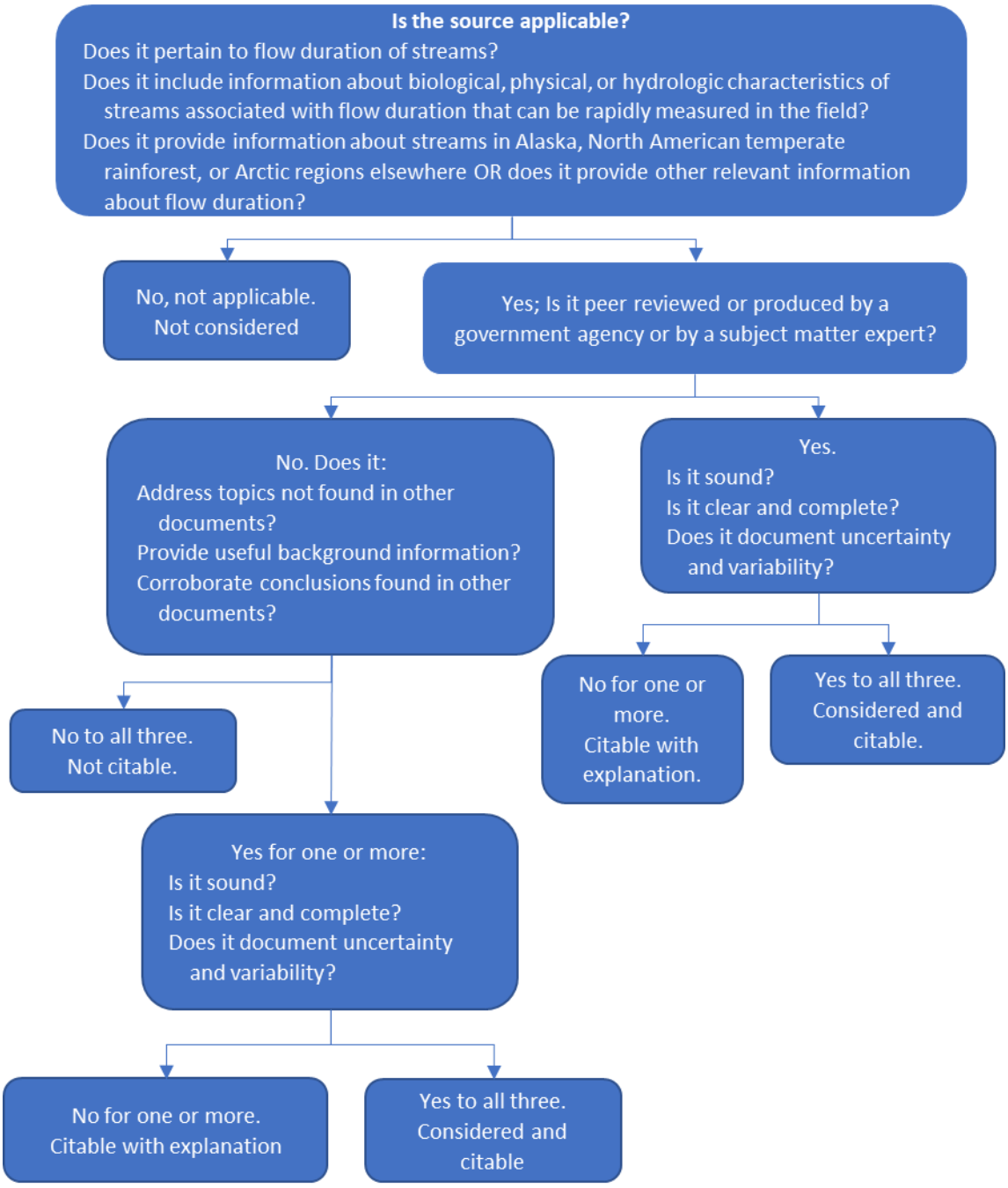


Figure 7. Decision tree for evaluating references.

2.3.2 Evaluating Information About Indicators

Each reference was reviewed to identify information about indicators of flow duration. First, the flow duration 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 text, figures, and tables, were reviewed for information about indicators associated with different flow 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

Eighteen methods available in January 2021 were considered to be appropriate for evaluating flow duration classes; two of these were developed outside of the U.S. No existing SDAMs appear to be used in Alaska; however, four are from regions that have similarities to hydrologic landscapes found in Alaska (Table 2), though none of these hydrologic landscapes include areas where permafrost is present. Table 3 summarizes 14 other methods for evaluating flow duration classes used in other regions of the U.S. or other countries. Methods developed for use in other parts of the U.S. 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. It is important to note that two included methods 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 was used to support jurisdictional determinations (though not in Alaska).

Table 5 summarizes which field indicators are used with each method, whereas Table 5 summarizes 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 Alaska study, with one exception (see Table 5); the rationale for including non-priority indicators is provided in the table.

Table 2. Potentially relevant methods for assessing flow duration, and their associated indicators, in Alaska.

Reference	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
Nadeau (2015)	Pacific Northwest (ID, OR, WA)	Yes; used by Corps Districts and EPA as supporting evidence of waters of the U.S. (WOTUS) jurisdiction	Perennial, intermittent, and ephemeral	Benthic macroinvertebrate, wetland plants, fish, amphibians/snakes Ancillary: riparian corridor	Slope Ancillary: 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 primarily used to test indicators for development of a data-driven 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
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 3. Methods for assessing flow duration and their associated indicators in other regions of the U.S. and in other countries.

Reference	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 Clean Water Act 401 ('waters of the state') and state-level rules (riparian buffers); used by Corps Wilmington District as supporting evidence of WOTUS 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

Reference	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
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; does not appear to be used by Corps Districts to support WOTUS jurisdction	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 WOTUS 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
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 WOTUS 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

Reference	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
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 Clean Water Act 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 WOTUS 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
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 WOTUS 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

Reference	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
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		
Bent and Steeves (2006)	Massachusetts (excluding SE coast)	No	Perennial and intermittent			Not field based — variables in equation: drainage area, areal % of sand and gravel deposits, areal % of forest land, and region (east or west)
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 WOTUS jurisdiction	Perennial and intermittent			Not field based – variables in equation: 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 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 regions most similar to parts of Alaska.

Indicator	Pacific Northwest	Oregon Interim Method	Alberta (Foothills)	Idaho	North Carolina	Temperate USA	Kentucky	Ohio	Fairfax County, VA	James City County, VA	Virginia	Tennessee	Western GA, NC, SC	New Mexico (Phase 1)	New Mexico (Phase 2)	Mediterranean	Czech Republic
Bankfull width and/or depth			X			X	X	X									
Maximum pool depth						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					
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			
Slope/Gradient	X		X	X		X	X	X									
Organic bridge			X														
Continuous logged data						X									X		
Groundwater observation		X			X	X		X		X		X		X			

Indicator	Pacific Northwest	Oregon Interim Method	Alberta (Foothills)	Idaho	North Carolina	Temperate USA	Kentucky	Ohio	Fairfax County, VA	James City County, VA	Virginia	Tennessee	Western GA, NC, SC	New Mexico (Phase 1)	New Mexico (Phase 2)	Mediterranean	Czech Republic
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)/observation of baseflow			X	X	X	X		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	
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			
Velocity						X											
Presence of geological formation that contributes to baseflow (Yorktown formation)										X							
Algae (includes alive or dead algal mats)/periphyton		X		X	X	X			X			X		X			
Lichen line		X[5]															
Bryophytes (includes streamer mosses)		X		X		X											
Fibrous roots in channel					X							X					
Wetland or aquatic vegetation in channel/immediate vicinity	X	X	X	X	X				X			X					
Upland vegetation in channel		X	X		X							X		X			
Distinct riparian corridor/differences in vegetation		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		
Aquatic macroinvertebrates[4] - Indicator taxa (e.g., EPT taxa)	X	X		X	X			X	X		X	X			X		X
Aquatic macroinvertebrates – Traits																	X

Indicator	Pacific Northwest	Oregon Interim Method	Alberta (Foothills)	Idaho	North Carolina	Temperate USA	Kentucky	Ohio	Fairfax County, VA	James City County, VA	Virginia	Tennessee	Western GA, NC, SC	New Mexico (Phase 1)	New Mexico (Phase 2)	Mediterranean	Czech Republic
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									
Reptiles – Presence	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		
Fish –Indicator taxa				X				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.

Table 5. Evaluation criteria (see Section 2.1) for indicators identified in the literature review.

Indicator	Consistency	Repeatability	Defensibility	Rapidness	Objectivity	**Priority Indicator**	Robustness	Practicality	**Proposed**
Bankfull width and/or depth	X	X		X	X	No	X	X	**No**
Maximum pool depth	X	X		X	X	No	X	X	**No**
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	**No[4]**
Evidence of active or relict floodplain		X		X		No	X	X	**No**
Presence of natural valley/degree of development	X	X		X		No		X	**No**
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	**No**
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**
Continuous logged data	X	X	X		X	No	X		**No**
Groundwater observation	X	X	X		X	No	X		**Yes[1,4]**
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)/ Observation of baseflow	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	**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	**No**
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**
Lichen line		X	X	X	X	No		X	**Yes[1]**
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**
Distinct riparian corridor/differences in 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	**No[3]**
Amphibians – Presence and/or Abundance and/or Diversity	X	X	X	X	X	Yes	X	X	**Yes[5]**
Amphibians – Indicator Taxa	X	X	X	X	X	Yes		X	**Yes[5]**
Reptiles – Presence	X	X	X	X	X	Yes	X	X	**No[3]**
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**
Evidence of thermokarst		X	X	X		No	X	X	**Yes[2]**
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**
Presence of aufeis	X	X	X	X		No	X	X	**Yes[2]**
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 used by the Oregon Interim Method (Topping et al. 2009); 2: Non-priority indicator proposed for inclusion because studies identified in Section 4 suggest a potential relationship with flow duration; 3: No freshwater species native to Alaska; 4: Only applicable outside of permafrost regions of Alaska; 5: Not applicable to the North Slope of Alaska.

* Identified in both AW and WM literature reviews

+ Identified in AW literature review

§ Identified in WM literature review

3.1 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 indicators: 1) presence of aquatic macroinvertebrates; 2) number of mayflies (order Ephemeroptera); 3) presence of perennial aquatic macroinvertebrate 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) reach slope. Single indicators such as the presence of fish and aquatic stages of amphibians may result in an "at least intermittent" classification. Ancillary indicators, such as evidence of sediment erosion or deposition, are also considered as contextual support for the flow duration determination. Indicators are measured objectively, without requiring subjective or qualitative visual assessments by practitioners. This data-driven method resulted from a three-state study (Idaho, Oregon, and Washington; Nadeau et al. 2015) of the Oregon Interim Method (Topping et al. 2009; see 3.2).

Indicators are evaluated with a simple branching flow-chart (Figure 8), and not all indicators are needed to make a flow duration determination at every site. Consequently, it is among the simplest tools to implement. This method strongly emphasizes biological indicators, including only one geomorphological indicator (slope) and no hydrological indicators.

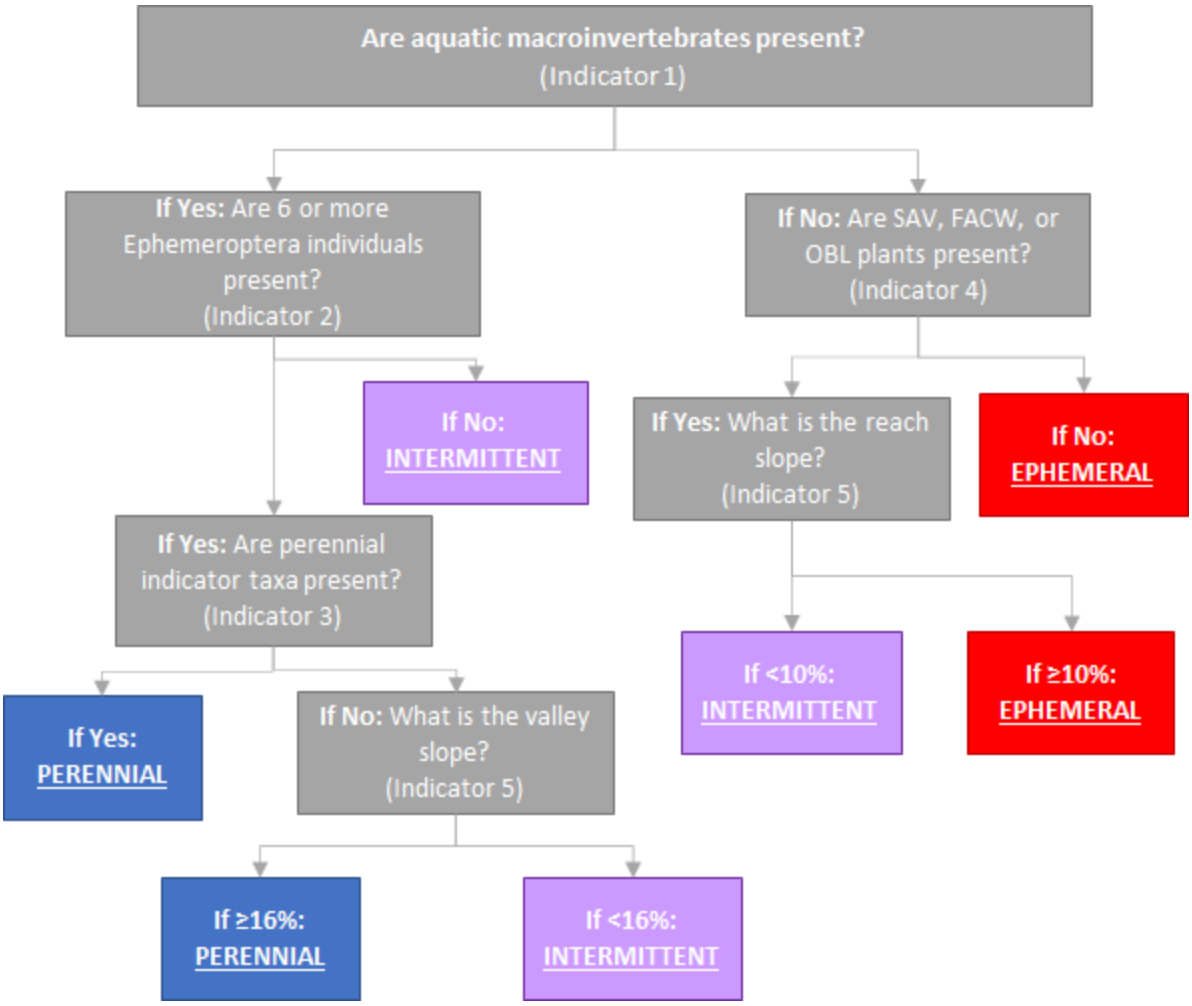


Figure 8. Decision tree used to determine streamflow duration class in the Pacific Northwest method (adapted from Nadeau 2015).

3.2 Oregon Interim Method

Prior to the development of the method of Nadeau (2015) for the Pacific Northwest, Topping et al. (2009) developed an SDAM for Oregon 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 override an "ephemeral" classification. In contrast to Nadeau (2015), assessing the strength of the indicators requires subjective visual assessments by practitioners.

3.3 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 6.

Table 6. 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 9 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 9. Characteristics of seepage-fed and fluvial channels in McCleary et al. (2012). Subscripts in original and provide details on the field methods.

3.4 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.

3.5 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 10, 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 10. NC SDAM general scoring guidance (from NC DWQ 2010).

This method applies within a state that is included in both the NE and SE study 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).

3.6 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 methods described is more comprehensive than the other listed methods, but no conclusive flow duration classification is drawn upon at the end of the analysis. 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.

3.7 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.

3.8 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 11. 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.

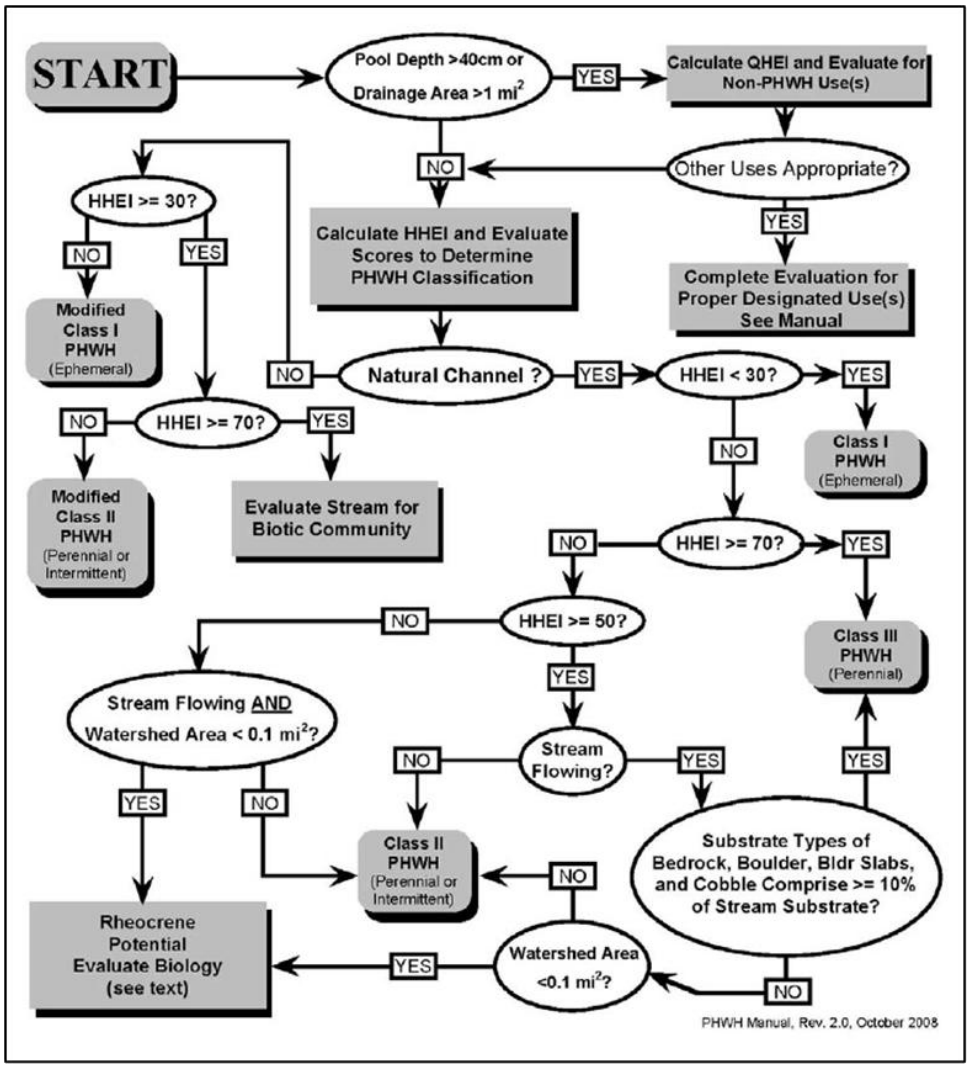


Figure 11. PHWH stream classification flow chart based on HHEI scoring (from Ohio EPA 2012).

3.9 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).

3.10 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.

3.11 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 12). 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 state 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 12. Primary indicators to determine if a channel is a stream or a WWC (from TDEQ 2011).

3.12 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 13). 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 13. Physical and biological criteria used to delineate flow types in Hansen (2001).

3.13 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 gages 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 7). Notably, this method may result in ambiguous situations (gray rows in Table 7), 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 7. 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

3.14 Mediterranean Europe

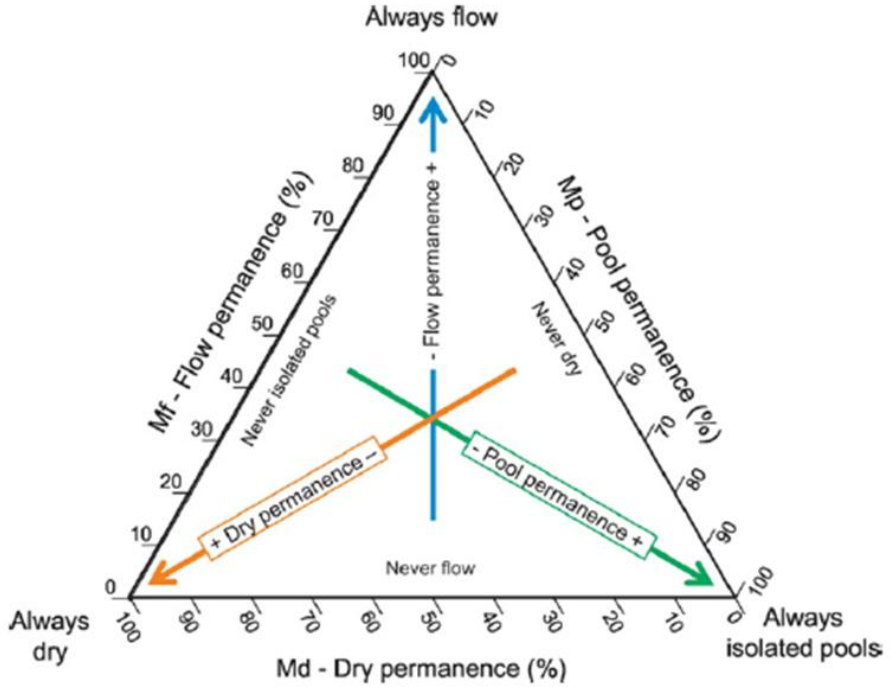
Prat et al. (2014) developed an assessment framework known as Mediterranean Intermittent River ManAGEment (MIRAGE) to identify the flow status of streams in order to guide selection of appropriate condition assessment tools based on biology, water chemistry, habitat, or other condition indicators. The 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 14.



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

3.15 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 15. Relationship between biodrought index scores and flow classes, from Straka et al. (2019).). 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 8).

Table 8. 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

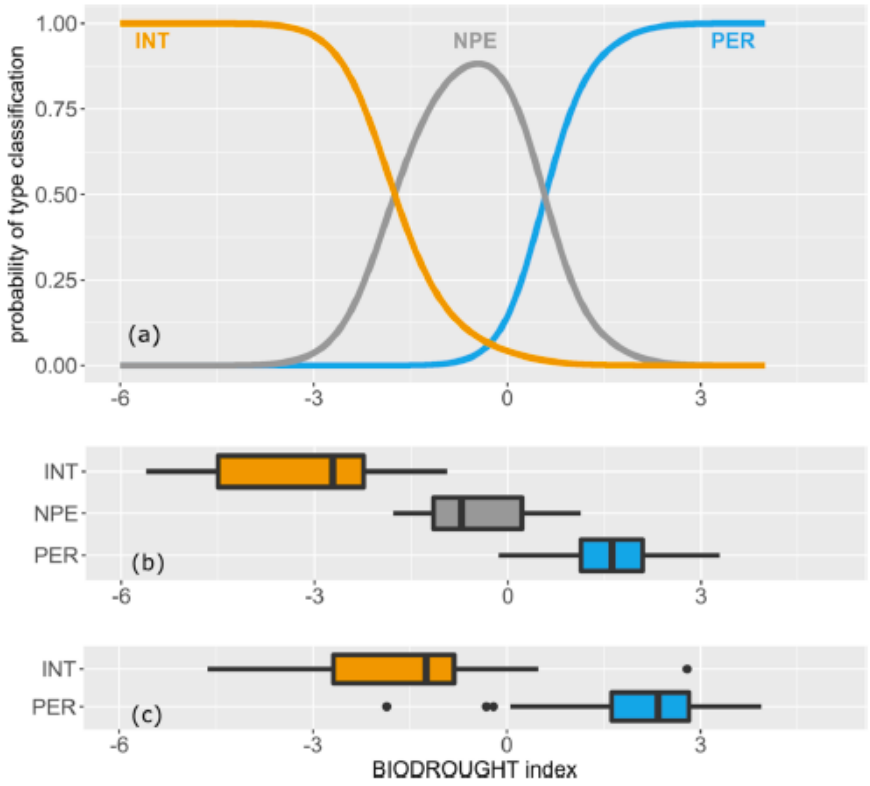


Figure 15. Relationship between biodrought index scores and flow classes, from Straka et al. (2019).Top panel shows the probability of classification as the index score increases. The second panel shows scores associated with calibration data. The bottom panel shows scores associated with independent 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.

3.16 Massachusetts and Vermont

Logistic regression equations were developed to determine the probability of a stream reach in Massachusetts and Vermont being perennial or intermittent. These are not field based methods but could be complementary 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 state

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).

4.0 INDICATORS IN ALASKA

A review of literature describing possible indicators of streamflow duration class in Alaska shows general support for those used in current flow duration assessment methods, though studies exploring flow duration and existing indicators in Alaska were scarce. We discuss each class of indicators and determine whether specific indicators should be included in the development of flow duration assessment methods in Alaska, with particular attention to the indicators included in Nadeau (2015) and Topping et al. (2009) where possible. All applicable references met the evaluation criteria outlined in Section 2.3.1.

4.1 Geomorphological Indicators

All of the studies pertaining to geomorphological indicators in Alaska found during this review are related to channel formation or entrenchment in areas of permafrost, with the majority from the North Slope. Of particular note are water tracks (also called ‘stripes’), which are common curvilinear features on hillslopes that preferentially fill with and route water in response to snowmelt and rainfall when the soil above continuous permafrost thaws in the

summer (Evans et al. 2020). McNamara et al. (1999) found that water tracks often begin at a drainage area size that generally supports channel formation in other regions; however, many water tracks do not have incised channels and flow during summer is mostly confined to the sub-surface, though occasional to frequent ponding may be present (Trochim et al. 2016). The authors postulate that permafrost may constrain the development of a hillslope channel network by restricting erosion.

Trochim et al. (2016) describes five different classes of water tracks, based on factors including width, slope, substrate type and thickness (organics, mineral, sand), and vegetation type and percent cover. Certain types of water tracks appeared to be associated with thermokarst activity. Thermokarst is a physical depression of the ground surface due to thawing permafrost (thermal erosion). Gooseff et al. (2009) observed that hillslope thermokarst is increasing in permafrost regions due to climate change. The mass wasting associated with permafrost thaw can lead to greater dissection of hillslopes and potential expansion of Arctic stream networks upslope. Of interest here is that more water tracks may have incised channels than in the past, which is consistent with findings by Osterkamp et al. (2009). This study found that there has been a dramatic increase in thermokarst 'gullies' in areas of tundra near Fairbanks, often occurring in water tracks.

Crawford and Stanley (2014) found that first-order streams underlain by permafrost (near Fairbanks) were straighter and deeper than expected given their placement in the drainage network. The authors theorize that this effect may partially be due to the presence of 'anchor ice' (ice attached to the streambed) in the channel, which dampens the effect of channel forming discharges during the snowmelt period. While the streams were not identified by flow duration, given their first-order status they may have a better chance of being non-perennial. However, the observations from this study may render potential indicators of flow duration such as entrenchment ratio and sinuosity less useful where permafrost is present.

Tufa Deposits

In alkaline waters rich in carbonate, deposits call tufa 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 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. While no sites in Alaska were described, similar areas of northwestern Canada were included in the review. 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

Three methods (Topping et al. 2009, NMED 2011, and Savage and Rabe 1979) identified in this review use the presence of seeps and/or springs to distinguish between flow duration types. Springs are an important part of the hydrological landscape on the North Slope of Alaska. Here, mountain and tundra 'spring' streams are warmer than those not fed by springs and usually flow perennially through the year, even during the winter when other streams of similar depth are frozen solid (Huryn and Hobbie 2012). In winter, spring streams also reliably form overflow ice or 'aufeis' where flow encounters channel ice or other obstructions as distance increases from the spring source or confluence with another system (Huryn et al. 2005). Aufeis is formed when flowing water is continually forced over river ice and freezes in successive sheets; therefore, the presence of aufeis likely indicates upstream springs. Masses of aufeis can be seen on aerial photos taken during winter and are often so large they persist into summer, when most other ice has melted (Huryn and Hobbie 2012). The presence of aufeis into summer may also have implications for downstream flow as its meltwater is slowly released during periods of greater evapotranspiration.

On the North Slope, Betts and Kane (2015) observed with instrumentation that two sites on the perennial Kuparuk River ceased flowing for short periods (<30 days, non-consecutive) during the summer, though isolated pools often remained. However, flow was observed above and below the instrumented reaches, indicating hyporheic flow in the active layer above permafrost. The authors theorize that larger thaw bulbs around the stream may provide a preferential pathway for flow during drier periods. Thaw bulbs are areas of unfrozen soil below streams and lakes in regions underlain by continuous permafrost. Larger thaw bulbs may be explained by the occurrence of unfrozen glacial moraines (unconsolidated material deposited by glaciers) along the stream channel (Kane et al. 2013).

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 (includes Pacific Northwest), identify wrack lines/drift deposits (woody or non-woody material) 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.

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. Similarly, in southeast Alaska, Bryant et al. (2007) observe that steps and step pools created by large wood are 'keystone' structures that increase bedform

complexity and greatly influence stream biological processes. There are 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 in WM streams. However, 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) reports woody jam 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 geomorphological and hydrological indicators, 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, GP, and NE/SE since biological indicators can be widespread; if a study is specific to Alaska or similar environments, it is indicated as such.

4.3.1 Aquatic macroinvertebrates

In general, studies from other regions 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. The Interim Oregon Method (Topping et al. 2009) uses a list of perennial and intermittent indicator taxa as support for a stream being at least intermittent even if the stream score is lower than the intermittent threshold. Except for the intermittent indicator taxa, the lists are almost identical (Table 9).

Table 9. Comparison of the perennial indicator taxa used in the Pacific Northwest and Interim Oregon SDAMS (Nadeau 2015; Topping et al. 2009). Note: larval indicators are for late-instar stages only.

Taxa[3]	PNW Method Perennial Indicator Families	Oregon Interim Method Perennial (P) or Intermittent (I) Indicator Families
Ephemeroptera (larvae)	No indicator families; uses abundance of Ephemeroptera (6 or more individuals)	None
Plecoptera (larvae)	Pternarcyidae[1], Perlidae[1]	Same as PNW (P); Capniidae, Nemouridae (I)
Trichoptera (larvae)	Philopotamidae[2], Hydropsychidae[2], Rhyacophilidae, Glossosomatidae	Same as PNW (P); Limnephilidae (I)
Coleoptera (larvae)	Elmidae[1], Psephenidae[1]	Same as PNW (P); larvae or adults of Dytiscidae, Hydrophilidae (I)
Odonata (larvae)	Gomphidae[1], Cordulegastridae[1], Calopterygidae[1]	Same as PNW (P); Lestidae[2] (I)
Megaloptera (larvae)	Corydalidae[1]	None
Mollusca (any life stage)	Any life stage of Unionidae[2], Ancylidae[1], Pleuroceridae[1], Hydrobiidae[1], Margaritiferidae[2]	Adults of *Juga* spp.[1] (Pleurocerid snail), Unionidae[2], Margaritiferidae[2] (P); none (I)

[1] These families are of very limited distribution in Alaska or are absent entirely.
[2] These families are not found on the North Slope.
[3] Larvae/nymphs/pupae only unless otherwise indicated.

As noted in Table 9, most of the perennial indicator taxa identified by the PNW and Oregon Interim methods are of limited distribution in Alaska or may be absent entirely from the state or certain regions (usually the North Slope; e.g., Bousquet et al. 2013, Burch 1982, Hudson and Armstrong 2010, Huryn and Hobbie 2012, Kendrick and Huryn 2014, Nedeau et al. 2009, Vineyard 1982). During the literature search, very few studies of the effects of flow duration on the macroinvertebrate community in Alaska were found. However, a good analog may be studies that explore the strategies of certain taxa to survive conditions where the entire water column freezes during winter (Tolonen et al. 2019; see Section 1.0) and most flow ceases (potentially even into the hyporheic zone). In addition, studies exploring flow duration and macroinvertebrates in other parts of the North American west coast temperate rainforest (U.S. and Canada) were found that might have some application for southeast Alaska, where this habitat also exists. Similarly, studies from other arctic environments (Canada, Sweden) may also have application in Alaska. Results from these studies are summarized in Table 10 and mostly deal with aquatic insects. These studies present their results at different taxonomic resolutions, ranging from genus and species to family level or higher.

Table 10: Studies from Alaska and similar regions of aquatic macroinvertebrates in different flow duration classes.

Reference	Region	Notes	Perennial/Permanent[1]	Intermittent/ Ephemeral/Frozen Conditions[1]
Banks (2005)	Central OR coast range (temperate rainforest)	Influence of flow duration (perennial and intermittent) and clearcut logging on benthic macroinvertebrates.	40 taxa unique to perennial sites (majority Diptera) including *Epeorus*, *Ironodes*, *Cinygmula, Drunella, Baetis*, *Chyranda centralis, Kathroperla,* and *Tipula*.	9 taxa unique to intermittent sites, including *Paraleuctra* and *Cryptochia*. *Wormaldia* had a preference for intermittent streams and *Despaxia augusta* were found in higher densities.
Cowan and Oswood (1984)	Sub-arctic Alaska (Fairbanks area)	Authors studied shredders on leaf packs in summer in Monument Creek, part of which freezes solid during winter (no flow duration specified; assumed perennial).	Most common taxa included *Tipula, Zapada, Ecclisomyia, Chyranda, Onocosmoecus*, and Capniidae.	
Crossman et al. (2013)	Sub-arctic Alaska (Denali NP)	Addresses influence of environmental instability on macroinvertebrate community of groundwater-fed streams, though does not include flow duration as a factor. Two streams were determined to be ephemeral.	No apparent differences in suite of macroinvertebrates based on flow duration alone, but it was observed that Chironomidae, Nemouridae, and Empididae used the hyporheic zone as a refuge, mostly for competitive advantage. Whereas Limnephilidae, Chloroperlidae, Simuliidae, and Baetidae used the hyporheic zone as a more permanent extension of surface habitat.	
Danks (1971)	Arctic (mostly Canada, Sweden, Greenland)	Details over-wintering strategies of Arctic chironomids in frozen habitats.		Some arctic chironomid taxa build winter cocoons to survive freezing, including *Psectrocladius, Tanytarsus*, and *Cricotopus;* others are known to tolerate freezing, including many in the Orthocladiinae and Chironominae (few in Tanypodinae).
Giberson et al. (2007)	Nunavut, Canada	Describes mayfly life cycle in areas where streams freeze to permafrost and typically dry in late summer.		*Baetis bundyae* was most common mayfly above treeline and was found in habitats that froze in the winter and dried up in late summer; however, its speedy development cycle likely allows it to avoid periods of drying and its freeze-tolerant eggs allow them to survive winter.

Huryn and Hobbie (2012)	North Slope, Alaska	Identifies some taxa found only in perennially flowing spring streams that do not freeze solid in winter (unable to tolerate freezing).	Examples of freezing intolerant species given include *Isoperla petersoni, Glossosoma nigrior*, and *Ecclisomyia conspersa*, as well as the 6 species of dragonflies and damselflies found on the North Slope, though these are mostly associated with tundra ponds (e.g., *Somatochlora sahlbergi* and *Enallagma cyathigerum*).	
Huryn et al. (2005)	North Slope, Alaska	Compares biological community in continuously flowing spring streams and those that freeze to the subsurface in winter (authors call these intermittent streams).	Perlodidae (e.g., *Arcynopteryx compacta* and *Isoperla sobria*) and *Zapada* were only associated with streams that did not freeze.	
Irons et al. (1993)	Sub-arctic Alaska (Fairbanks area)	Explores over-wintering strategies of macroinvertebrates.	Unfrozen streambed contained many more taxa than frozen, including baetid and heptageniid mayflies, nemourid, capniid, and perlodid stoneflies, rhaycophilid caddisflies, tipulids, and simuliids.	Chironomidae and Empididae (specifically *Chelifera*) larvae were found in frozen sediments and had relatively good survivorship when thawed.
Muchow and Richardson (2000)	Vancouver, British Columbia (temperate rainforest)	Compares macroinvertebrates (focusing on Plecoptera) in perennial and intermittent streams.	Plecoptera found only in continuous flow sites include *Nemoura*, *Paraleuctra vershina*, and *Sweltsa*.	Plecoptera species found in intermittent streams were subset of those found in continuous flow sites. *Despaxia augusta* was often largest contributor to biomass.
Olsson (1981)	Northern Sweden	Describes macroinvertebrates taken from frozen sediments and their survival rate once thawed.		Found *Gyraulus acronicus*, *Pisidium*, Tubificidae, Orthocladiinae, and Chironomidae in frozen sediments, all with a good survival rate once thawed. Also found trichopterans (e.g., *Molanna*) in frozen sediments with lower rates of survival once thawed.

Price et al. (2003)	Vancouver Island, British Columbia (temperate rainforest)	Compares macroinvertebrates in perennial, intermittent, and ephemeral streams. Most taxa were found in all flow types, to some degree.	More Ephemeroptera in perennial streams, with overall richness similar to intermittent streams.	Four taxa only found in intermittent streams including two with distributions in Alaska: *Wormaldia* and *Hydropsyche*. Fewer EPT and lower overall richness in ephemeral streams compared to intermittent and perennial streams.
Walters et al. (2009)	North Slope, Alaska	Explores freeze tolerance in *Nemoura arctica*.		*Nemoura arctica* is able to overwinter in a stream that freezes to the subsurface during winter (down to -15 C), with relatively good survivorship when thawed. Nymphs were found encased in ice during winter.
Windsor et al. (2017)	Sub-arctic Alaska (Denali NP)	Explores differences in macroinvertebrate community due to flow permanence (perennial or ephemeral) in ground-water fed, glacierized catchment.	Perennial streams had greater macroinvertebrate total abundance and taxonomic richness.	Ephemeral streams had much greater abundances of Chloroperlidae, Perlodidae, Leuctride, and Capniidae (*Plumiperla, Isoperla*, *Perlomyia*, and *Capnia*) than perennial streams, likely because these species take advantage of the hyporheic zone.

[1] For studies outside Alaska, species listed emphasize taxa that might be encountered in Alaska.

Below, major groups of aquatic macroinvertebrates are considered in relation to flow duration; cited references may also draw from the AW, WM, GP, and NE/SE 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 Alaska. Straka et al. (2019) identified this taxon as an indicator of intermittent or nearly perennial Czech streams, along with numerous taxa in Physidae, Planorbidae, and Lymnaeidae. A number of Lymnaeid taxa were also indicators of perennial flow, along with *Ancylus fluviatilis* (Planorbidae). There were no studies on snails and flow duration specific to Alaska, though Olsson (1981) found that members of Planorbidae (*Gyraulus acronicus*) survived freezing of the water column in Sweden; this genus is also represented in Alaska. In the NE/SE, Eaton and Vander Vorste (2012) observed members of Physidae and Lymnaeidae only in perennial streams. However, Davis et al. (2003) found Physid snails (*Physella* sp.) in Georgia streams with less than perennial flow, which is more consistent with studies in the GP (Bramblett and Fausch 1991, King et al. 2015, and Miller and Golladay 1996). Physid snails are under-represented in Alaska (Burch 1982), so their use as a flow duration indicator may be limited.

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 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. There were no studies found on mussels and flow duration specific to Alaska or similar areas during this review. There are only 3 representatives of the Unionidae (*Anodonta kennerlyi* and *A. beringiana*) and Margaritiferidae (*Margaritifera falcata*) in Alaska (Nedeau et al. 2009) and all appear to require habitats that have permanent water (rivers, lakes, and reservoirs). Fingernail clams (Sphaeriidae) are not generally treated as a perennial indicator taxon, at least without other evidence the stream is perennial (NCDWQ 2010), though some support for this classification is found in Lusardi et al. (2016), Kelso (2012), and Kelso and Entrenkin (2018). However, Straka (2019) identified *Pisidium* sp. (pea clams) as an indicator of intermittent flow, and Davis et al. (2003) found this taxon in intermittent streams in Georgia. Olsson (1981) found that *Pisidium* sp. could tolerate freezing of the water column, which suggests that some species may have strategies for dealing with less than perennial water flow.

Ephemeroptera (mayflies)

No mayfly families are considered to be indicators of perennial flow in the PNW method (Nadeau 2015); however, if at least 6 mayfly individuals are present, the method indicates a greater chance of perennial flow. This outcome is supported by the findings of Price et al.

(2013) from Vancouver Island, BC where more Ephemeroptera were found in perennial streams as compared to intermittent and ephemeral streams. In a study in the temperate rainforest of Oregon, Banks (2005) found several mayfly genera with distributions in Alaska (Randolph and McCafferty 2005) only in perennial streams, representing Baetidae, Ephemerellidae, and Heptageniidae. Similarly, Eaton and Vander Vorste (2012) found representatives of these three families only in perennial headwater streams across several states in the NE/SE. This finding is supported in the NE/SE region by Delucchi (1988), Santos and Stevenson (2011), and Smith et al. (2017). Kelso (2012) observed *Acentrella* sp. (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.

Studies cited in literature reviews informing development of SDAMs for the AW and GP 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*). However, for baetids, it is important to note that, at least on the Alaskan North Slope, their life cycle may allow them to avoid periods of intermittent flow in systems that dry in the late summer (Giberson et al. 2007). Giberson et al. (2007) observed that *Baetis bundyae* has a freeze-tolerant egg stage and short development cycle that allows it to take advantage of the availability of flowing water during the snowmelt period, with emergence generally before these systems experience drying in August.

Plecoptera (stoneflies)

Both the stonefly families that are considered perennial indicators in the PNW and Oregon Interim methods, Pteronarcyidae and Perlidae, have limited distributions in Alaska or are absent entirely. The Oregon Interim method includes Capniidae and Nemouridae as indicators of intermittent stream flow; both families are well-represented in Alaska. Cowan and Oswood (1989) found that *Zapada* sp. (Nemouridae) and Capniidae were some of the most common shredder taxa in a perennial stream near Fairbanks. On the North Slope, *Zapada* sp. were also associated with continually flowing spring streams that do not freeze (Huryn et al. 2005). In a study near Vancouver, BC, *Nemoura* sp. were one of the only Plecoptera genera found exclusively in streams with continuous flow near Vancouver, BC (Muchow and Richardson 2000). However, Walters et al. (2009) found that, on the North Slope, *Nemoura arctica* can overwinter as nymphs in streams that are frozen to the subsurface during winter—these streams may not meet the definition of intermittent, but it does suggest that this species has strategies to cope with less than continuous water flow. Windsor et al. (2017) found that, while *Capnia* sp. was not exclusively associated with ephemeral streams, their abundances were greater in these systems, likely because they take advantage of the hyporheic zone.

The families Perlodidae, Chloroperlidae, and Leuctridae are also well-represented in Alaska. In Alaska and similar environments, there is some evidence to suggest that Perlodidae and Chloroperlidae may have some preference for perennially flowing streams (Banks 2005, Huryn

and Hobbie 2012, Huyrn et al. 2005, Muchow and Richardson 2000), though this preference may be related to limited freeze tolerance, at least on the North Slope. However, Windsor et al. (2017) found Chloroperlidae, Perlodidae, and Leuctridae in both perennial and ephemeral streams, with greater abundances in ephemeral streams potentially attributable to their use of the hyporheic zone. *Despaxia augusta* is a leuctrid stonefly with a two-year life cycle; however, both Banks (2005) and Muchow and Richardson (2000) found this species in greater abundance in intermittent streams, even when surface dry, which is similar to findings from Windsor (2017). Banks (2005) found *Paraleuctra* sp. (Leuctridae) only in intermittent streams while Muchow and Richardson found *Paraleuctra vershina* only in perennial streams, suggesting that differences in flow duration preference may occur at the genus level.

Trichoptera (caddisflies)

Four Trichopteran families (Table 9) are used as perennial indicators in the PNW method, all of which are found to some degree in Alaska, though two have restricted ranges. One of these is Hydropsychidae; Price et al. (2003) found *Hydropsyche* sp. only in intermittent streams on Vancouver Island. In contrast, six studies in the NE/SE, WM, and GP support the use of this family as a perennial indicator (Bramblett and Fausch 1991, Burk and Kenndedy 2013, Fritz and Dodds 2002, Miller and Brasher 2011, and Smith et al. 2017, Stagliano 2005). *Wormaldia* sp. (Philopotamidae) showed a preference for intermittent streams in Oregon (Banks 2005) and were found only in intermittent streams on Vancouver Island (Price et al. 2003).

The families Philopotamidae and Rhyacophilidae are supported as indicators of perennial flow in the AW and GP (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 is considered an indicator of intermittent stream flow in the Oregon Interim method, though Banks (2005) had one taxa indicative of perennial flow (*Chyranda centralis*) and one indicative of intermittent flow (*Cryptochia* sp.).

Staka et al. (2019) identified a handful of indicator species for intermittent flows in Czech streams (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, which are considered perennial indicator taxa in the PNW method (2015), do not occur in Alaska (Bousquet et al. 2013). In addition, information on Coleopteran families and flow duration in Alaska and similar environments was scarce to absent. The families Dysticidae and Hydrophilidae are considered indicators of intermittent

flow in the Oregon Interim method (Topping et al. 2009), both of which are well-represented in Alaska (Bousquet et al. 2013), but as above, little regional information pertinent to flow duration was found for these families.

In the AW and WM, studies supported the use of Hydrophilidae as indicators of intermittent flow (Bonada et al. 2006, Bogan and Lytle 2007). Straka et al. (2019) identified several indicators of intermittent flow in Czech streams (mostly Dytiscidae, Hydrophilidae, Helophoridae, and Hydraenidae), as well perennial streams (Dytiscidae, Gryinidae, Hydraenidae, and Scirtidae).

Odonata (dragonflies and damselflies)

The families identified as perennial indicator taxa in the PNW method (Table 9) are of very limited distribution in Alaska or are absent entirely (Hudson and Armstrong 2010). Regionally specific information on other Odonata families and flow duration is also scarce to absent.

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)

Megaloptera appear to be absent or extremely rare across Alaska and are therefore not discussed further (Oswood 1989).

Diptera (true flies, craneflies)

The Diptera are abundant and widespread in Alaska, particularly on the North Slope (Huryn and Hobbie 2012); however, no Diptera are considered to be perennial or intermittent indicators in the PNW or Oregon Interim methods. Given their northern distribution, it is not surprising that many dipterans (mostly Chironomidae and Empididae) appear to be freeze tolerant, with some forming winter cocoons (Danks 1971, Irons et al. 1993, Olsson 1981). As with some mollusks and Plecoptera (above), this ability suggests that these families have strategies to deal with less than perennial water flow. *Tipula* sp. (Tipulidae) were found only in perennial streams in the Oregon coastal range (Banks 2005) and were associated with a perennial stream near Fairbanks (Cowan and Oswood 1984). However, *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 the AW and WM (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 taxonomically identifying genera and families within this group in the field may make them impractical for use in a field-based flow duration assessment method.

Other aquatic invertebrates

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 ostracods 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, ostracods, copepods, and cladocerans) have resting egg stages that can resist dry periods of a year or more and also have the ability to tolerate freezing (tadpole and fairy shrimp; Huryn & Hobbie 2012). 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.

No crayfish are native to Alaska, so no discussion of this taxon is presented.

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. In tundra environments, macroalgal growth is naturally inhibited by low phosphorus levels in the soil and may only cover 1-10% of the streambed even when water flow is continuous (Sheath et al. 1996)

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 the Oregon Interim method (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). On the North Slope of Alaska, the *Sphagnum* community differs between water tracks and intertrack tundra (see Section 4.1). In water tracks, the following species were present: *Sphagnum girgensohnii, S. angustifolium, S. squarrosum*, and *S. warnstofii* (among others). On the other hand, intertrack tundra included species such as *S. fuscum* and *S. rubellum* (Murray et al. 1989). Sphagnum growth rates were also higher in water tracks than on intertrack tundra, though these rates could also be affected by thickness of the overstory vegetation. Desiccation tolerance of two stream bryophyte taxa from the Kuparuk River, *Schistidium agassizii* and *Hygrohypnum* spp. (*H. alpestre* and *H. ochraceum*), were compared in a laboratory experiment (Arscott et al. 2000). Experimental desiccation impacted photosynthesis of *Hygrohypnum* spp. more than *S. agassizzii*. The different responses aligned with observed differences in their distribution in the river. The streamer moss, *Hygrohypnum* spp., was rarely observed on streambed substrates that were intermittently dry, whereas the cushion moss, *S. agassizzii*, was commonly growing on substrate that was periodically dry (Arscott et al. 2000).

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 the PNW method (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. Potentially confounding this indicator are the high prevalence of wetlands on the Alaskan North Slope (Hall et al. 1994).

All the regionally specific studies of vegetation and flow duration are from the North Slope and largely deal with typical streamside vegetation and vegetation among water tracks (see Section 4.1) with different surface flow durations (Table 11). Wetland indicator status is taken from the 2018 National Wetland Plant List for Alaska.

Table 11. Vegetation associated with flow-duration classes.

Reference	Notes	Perennial	Intermittent/Ephemeral
Harms et al. 2019	Documented vegetation in a water track with perennial surface flow and one with ephemeral surface flow	Associated taxa: *Carex aquatilis* (OBL), *C. bigelowii* (FAC)	Associated taxa: *Betula nana* (FAC), *Salix pulchra* (FACW)
Huryn & Hobbie 2012	Characteristic riparian plants associated with streamside vegetation	Associated taxa: *Populus balsamifera* (FACU), *Salix alaxensis* (FAC), *S. pulchra*, *Hippuris vulgaris* (OBL), *Caltha palustris* (OBL), *Sparganium angustifolium* (OBL)	
Walker et al. 1994	Typifies vegetative communities of water tracks and riparian areas in Arctic foothills	Associated taxa: Water tracks carrying water throughout the summer had *Salix pulchra* overstory and *Eriophorum angustifolium* (OBL) understory, often with *Rubus chamaemorus* (FACW); *Salix alaxensis* and *S. richardsonii* (FACW) are typical of riparian margins and river bars.	Associated taxa: *Betula nana* is common on margins of water tracks and *E. vaginatum* (FACW) tends to be found at water tracks with no flowing water.

4.3.5 Vertebrates

<u>Amphibians and Reptiles</u>

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, while the Oregon Interim method includes the strength of presence of these species (strong, moderate, weak, or absent) in its scoring. The lists for both are the same; for amphibians, five

of the six species native to Alaska are included, as are one of the two species that have been introduced (ADFG 2006; Table 12). There are no freshwater reptiles native to Alaska.

Table 12. Water dependency status of amphibian species present in Alaska.

Species Present in Alaska		Water Dependent Life Stage (from Nadeau 2015)			
Scientific Name	**Common Name**	**Eggs**	**Larva/ Tadpole**	**Juvenile**	**Adult**
Rana luteiventris	Columbia spotted frog	OBL	OBL	OBL	OBL
Ambystoma macrodactylum	Long-toed salamander	OBL	OBL	FACW	FACW
Ambystoma gracile	Northwestern salamander	OBL	OBL	FACW	FACW
Pseudacris regilla	Pacific chorus frog[1]	Not considered a FACW or OBL 'wet' species at any life stage by Nadeau 2015[2]			
Rana draytonii (formerly *aurora)*	Red-legged frog[1]	OBL	OBL	FACW	FACW
Taricha granulosa	Rough-skinned newt	OBL	OBL	FAC	FAC
Bufo [Anaxyrus] boreas	Western toad	OBL	OBL	FAC	FAC
Rana [Lithobates] sylvatica	Wood frog	N/A (does not occur in the PNW)			

[1] Introduced to Alaska; restricted to Alexander archipelago.
[2] Range overlaps area covered by PNW method (Nadeau 2015) but is not considered to have a water dependent life stage.

Most of the species native to Alaska are restricted to the southeast part of the state and are at the northern end of their geographic ranges; exceptions to this rule are western toad and wood frog, which are more widespread. The wood frog is the only amphibian in Alaska that ranges above the Arctic Circle and is freeze tolerant (ADFG 2006; Tessler 2008). Wood frogs require shallow bodies of permanent or ephemeral water to lay eggs and are likely obligately dependent on water during the egg and tadpole stages.

Fish

Much like with certain amphibians, the PNW (Nadeau 2015) and Oregon Interim methods allow the presence of fish (except *Gambusia* sp. in Nadeau 2015, if only species present) to determine if a stream is at least intermittent. In the case of the Oregon Interim method, the presence of fish can supersede a stream score less than the intermittent threshold. There were no regionally specific studies related to fish and flow duration found during this review, except for one with indirect evidence. Arp et al. (2015) conducted a study of beaded streams on the North Slope, where it was hypothesized that the characteristic 'beaded' pools were able to retain

thawed sediment or even free water during the winter due to greater insulation by snow. When augering holes in these pools to measure the amount of unfrozen water, in some cases live fish (Alaska blackfish, *Dallia pectoralis*) were found beneath the ice. These fish would have to be able to tolerate low oxygen levels present in these pools that might mimic conditions within isolated pools in drying streams.

5.0 PROPOSED INDICATORS

Should an Alaskan SDAM be developed, we propose evaluating indicators included in the Pacific Northwest (Nadeau 2015) and Oregon Interim methods (Topping et al. 2009), including some additional indicators with positive evidence for determining flow duration in the primary literature, as well as any priority indicators from Table 5 (see Section 3) not already included. Some indicators are proposed only to be evaluated (or not) in certain regions or circumstances; these instances are noted below.

Geomorphological indicators

- Slope (Nadeau 2015)
- Continuous bed and bank (Topping et al. 2009)
- Sinuosity of channel along thalweg (Topping et al. 2009)
- In-channel structure (Topping et al. 2009)
- Soil texture or stream substrate sorting (Topping et al. 2009)
- Erosional features (e.g., undercut banks, scour marks; Topping et al. 2009)
- Depositional features (e.g., bars, fresh alluvial deposits; Topping et al. 2009)
- Headcuts and grade controls (Topping et al. 2009)
- Entrenchment ratio (Fritz et al. 2008; Johnson et al. 2009)
- Bankfull width and depth (Fritz et al. 2008; Johnson et al. 2009)
- Evidence of thermokarst (evaluate only in areas where permafrost is present; Gooseff et al. 2009, Osterkamp et al. 2009)

Hydrologic indicators

- Evidence of groundwater discharge (evaluate only where permafrost is not present) or hyporheic saturation (Topping et al. 2009)
- Seeps and springs (Topping et al. 2009)
- Evenly dispersed leaf litter and loose debris (Topping et al. 2009)
- Debris piles and wrack lines (Topping et al. 2009)
- Redoximorphic features in the toe of bank/soil-based evidence of high-water table or perched conditions (Topping et al. 2009)
- Presence of aufeis (evaluate only on North Slope; Huryn et al. 2005, Huryn and Hobbie 2012)
- Number of woody jams within 10 m of the reach (Mersel and Lichvar 2014)

Biological indicators

Aquatic macroinvertebrates

- Presence of aquatic macroinvertebrates (Nadeau 2015; Topping et al. 2009). Early instars, partial terrestrial taxa, and aerially dispersing life stages will be noted separately, if encountered. Includes aquatic mollusks.
- Abundance of mayflies (Nadeau 2015). Again, early instars will be ignored.
- Presence of perennial and intermittent indicator taxa (Nadeau 2015, Topping et al. 2009); includes only those taxa found in Alaska. To facilitate this indicator, benthic macroinvertebrates will be identified to the following taxonomic levels:
    - Family: Aquatic Insects and Mollusks
    - Superorder or Order: Aquatic Mites
    - 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, Bryophytes, Lichen

- Presence of live or dead algal mats (Topping et al. 2009)
- Presence of streamer mosses (Topping et al. 2009)
- Lichen line (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 and rooted upland plants in thalweg (Topping et al. 2009)
- Presence of wetland plants (includes FACW and OBL; Nadeau 2015, Topping et al. 2009) Regional plant lists encompassing the Alaska region shall be used (Lichvar et al. 2016)
- Distinct riparian vegetation corridor (Topping et al. 2009)

Vertebrates

- Presence of aquatic stage amphibians (do not evaluate on North Slope; Nadeau 2015, Topping et al. 2009); identify to genus
- Presence of fish (Nadeau 2015, Topping et al. 2009)

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Note, references gathered, evaluated and used in 2021.

6.1 Flow duration assessment methods

Here we present the references reviewed for methodology or methodology validation in determining flow duration classes. Methods that were excluded based on the criteria in Figure 7 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 References*".

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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 searches shown in Table 1 in the main document.

Table A-1 contains the screening information for literature with potential to provide baseline or validation sites. Included are sites that may not meet the definition of 'intermittent' in terms of drying but that may freeze to the subsurface in winter. **NOTE**: Indicator and method references are found in Section 6.0; all others (starred) are at the end of this Appendix.

Table A-1. Literature Screening for Potential Alaska 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.

Reference	Flow Classes and Definition (where available)	How is Flow Class/Winter Flow Determined?	Year Work Conducted	Provided Locality Information
Arp et al. 2015	None—beaded streams with pools that did not fully freeze	Augerings	2010-2013	Creek names where pools were found are given, but no other identifying info is provided
Best et al. 2005*	None—bedfast ice (completely frozen) or ice with flowing water during winter	Ground-penetrating radar; borings	2001	No coordinates, but a map is shown of locations along Kuparuk and Toolik Rivers.
Betts & Kane (2015)	Periodically intermittent--stream reaches with only hyporheic flow; average number of no flow days just under 30.	Observations, gages	2010-2012	General site coordinates are given, map of reach locations shown (Kuparuk River)
Crossman et al. 2013	Perennial and ephemeral--Perennial reaches had instream temperatures greater than 0 degrees all year, with flow likely persisting under snowpack; Ephemeral reaches had instream temperatures fall significantly below 0 degrees during winter or were observed to be dry	Temperature, observation	2008	Shows diagram of perennial and ephemeral reaches in Tolkat River floodplain and gives general site coordinates
Harms et al. 2019	Perennial and ephemeral—not defined	Weirs	2012-2014	Shows diagram of perennial and ephemeral surface flow water tracks on an aerial, with landmarks identified.
Heim et al. 2019*	Perennial and ephemeral—Perennial reaches flow all summer, ephemeral reaches flow only during spring run-off (June). All stream channels are frozen solid in winter.	Flow records (2009-2015)	2013	No coordinates; general location map and map showing diagram of where reaches are in relation to Crea Creek

Reference	Flow Classes and Definition (where available)	How is Flow Class/Winter Flow Determined?	Year Work Conducted	Provided Locality Information
Huryn & Hobbie 2012	Perennially flowing springs—streams do not freeze (North Slope)	Observations	Late 2000's/early 2010's	Coordinates for some spring streams, other identifying info
Huryn et al. 2005	None—spring (flow all year, do not freeze) and non-spring (freeze solid in winter)	Water temperature in winter (for some); absence of freeze intolerant indicators for others	1997-2004	General location map of stream sampling sites. Not very detailed.
Jones et al. 2013*	None—beaded streams with pools that did not fully freeze	Ground-penetrating radar, point measurements	2013	Pool coordinates are provided, map with frozen and only partially frozen water bodes (may be some of same pools as Arp et al. 2015)
Rushlow & Godsey 2017*	None—water tracks, did not define flow	N/A (used weirs but did not elaborate on flow duration	2013-2014	Larger set of water tracks used in Harms et al (2019). Shows diagram of water tracks on an aerial, with landmarks identified.
Walters et al. 2009	None—stream freezes solid in winter	Temperature, observation	2005-2007	West Fork of the North Fork of the Chandalar River; approximate coordinates are given
Windsor et al. 2017	Perennial and ephemeral--ephemeral streams were frozen solid during winter or had intermittent periods and/or drying during summer	Temperature at streambed as documented in Brown et al. (2006)	2014-2015	Map and coordinates of five main sites (12 total sites when counting sub-sites of these main sites; coordinates are not given for sub-sites)

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