Review of Flow Duration Methods and Indicators of Flow Duration in the Scientific Literature: Great Plains of the United States

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Prepared by:

Amy James
Ecosystem Planning and Restoration
Cary, NC

Kenneth McCune
Southern California Coastal Water Research Project
Costa Mesa, CA

Raphael Mazor
Southern California Coastal Water Research Project
Costa Mesa, CA

In collaboration with the U.S. Environmental Protection Agency's Streamflow Duration Assessment Method Project Delivery Team:

Ken Fritz
Office of Research and Development
Cincinnati, OH

Tracie Nadeau
Office of Wetlands, Oceans, and Watersheds
Portland, OR

Julie Kelso
Office of Wetlands, Oceans, and Watersheds
ORISE Fellow
Washington, DC

Brain Topping
Office of Wetlands, Oceans, and Watersheds
Washington, DC

Rachel Harrington
Office of Wetlands, Oceans, and Watersheds
Washington, DC

The following members of the National Steering Committee, and the Regional Steering Committee for the Great Plains, provided input and technical review:

National

Tunis McElwain
U.S. Army Corps of Engineers
Regulatory Branch
Washington, DC

Matt Wilson
U.S. Army Corps of Engineers
Regulatory Branch
Washington, DC

Gabrielle David
U.S. Army Corps of Engineers
Engineer Research and Development Center
Hanover, NH

Rose Kwok
U.S. Environmental Protection Agency
Office of Wetlands, Oceans and Watersheds
Washington, DC

Regional

Kerryann Weaver
U.S. Environmental Protection Agency
Region 5
Chicago, IL

Ed Hammer
U.S. Environmental Protection Agency
Region 5
Chicago, IL

Loribeth Tanner
U.S. Environmental Protection Agency
Region 6
Dallas, TX

Shawn Henderson
U.S. Environmental Protection Agency
Region 7
Lenexa, KS

Jason Daniels
U.S. Environmental Protection Agency
Region 7
Lenexa, KS

Billy Bunch
U.S. Environmental Protection Agency
Region 8
Denver, CO

Rob Hoffman
U.S. Army Corps of Engineers
Oklahoma District
Tulsa, OK

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Cover Photos

Photos are the property of the U.S. Environmental Protection Agency and were taken as part of data collection efforts for development of a Streamflow Duration Assessment Method in the Great Plains.

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1.0 STATEMENT OF THE 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 Great Plains (GP), 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 GP, following the process of Fritz et al. (2020). Additionally, information on potential study sites of known hydrology will be included, as gleaned from the existing literature, and from input from the Regional Steering Committee and other practitioners working in the GP, where possible.

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

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

The GP, within the context of this review, is considered those areas largely dominated by native prairie-type vegetation (tall-, short-, and mixed grass) that generally receive less than 40 inches of precipitation a year. However, it is important to note that significant forested areas are also found in the northeast part of this region as defined, where average yearly rainfall totals are closer to the upper end of the range (30 to 40 inches). The GP can be divided into a ‘northern’ and ‘southern’ section based on the importance of snowmelt to river discharge, as the boundary between north and south approximately follows the line south of which mean annual snowfall is less than 0.7 m (2 ft; Wohl et al. 2016). States within this region include Iowa, Kansas, Minnesota, Nebraska, North and South Dakota, and Wisconsin, as well as portions of Colorado, Michigan, Missouri, Montana, New Mexico, Oklahoma, Texas, and Wyoming. (Figure 1).

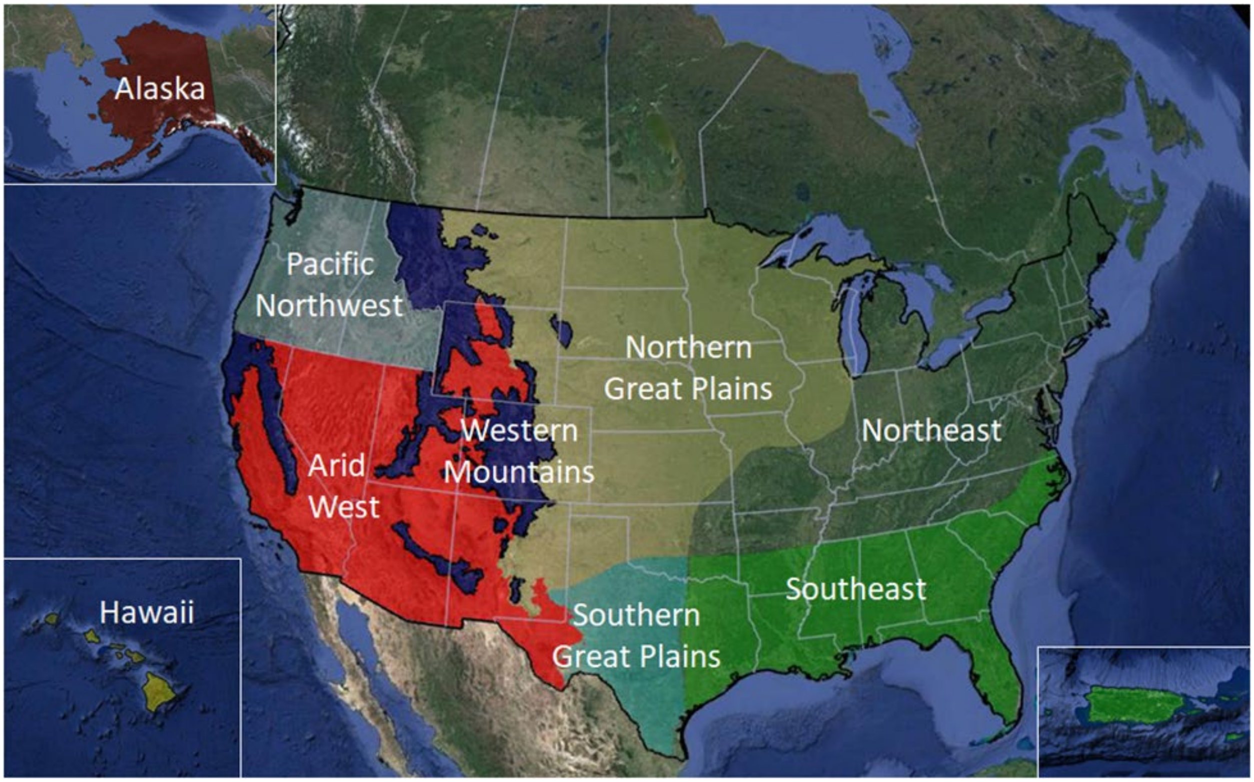

Figure 1. Map of flow duration regions, showing the northern and southern Great Plains. The Great Plains, Northeast, and Southeast regions were derived from the 'Ordinary High-Water Mark (OHWM) Scientific Support Document' (Wohl et al. 2016).

2.1 General approach

To date, flow duration literature reviews have been completed for the Arid West (AW; McCune and Mazor 2019) and the Western Mountains (WM; McCune and Mazor 2021) regions. For the GP literature review, existing flow duration assessment methods, data sources, and indicators identified in these previous literature reviews were reevaluated for their applicability to the GP. Further queries of literature databases were conducted to identify and evaluate any additional flow duration methods, data sources, and indicators that should be considered specifically for the GP.

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

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

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

Defensibility: Does the indicator have a rational or mechanistic relationship with flow duration in the region being considered? This aspect was assessed based on personal knowledge of ephemeral and intermittent stream systems in these regions. 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 its effectiveness in determining flow-duration classes, if available.

The list of potential indicators meeting most of these criteria resulted in a shortened list of priority indicators for further evaluation. This list of priority indicators 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 and/or observe the indicator in the present study? For example, if special permits are required for assessment, an indicator may be inappropriate for further investigation.

Based on these criteria, a final list of possible indicators of flow duration were selected to serve as the basis for field data collection in the GP. The objective here is to identify indicators that can be combined and evaluated as an SDAM for the GP region. A subsequent objective is to see how well that preliminary SDAM works compared to an SDAM developed for the Pacific Northwest (Nadeau 2015) and the method developed by the New Mexico Environment Department (NMED 2011).

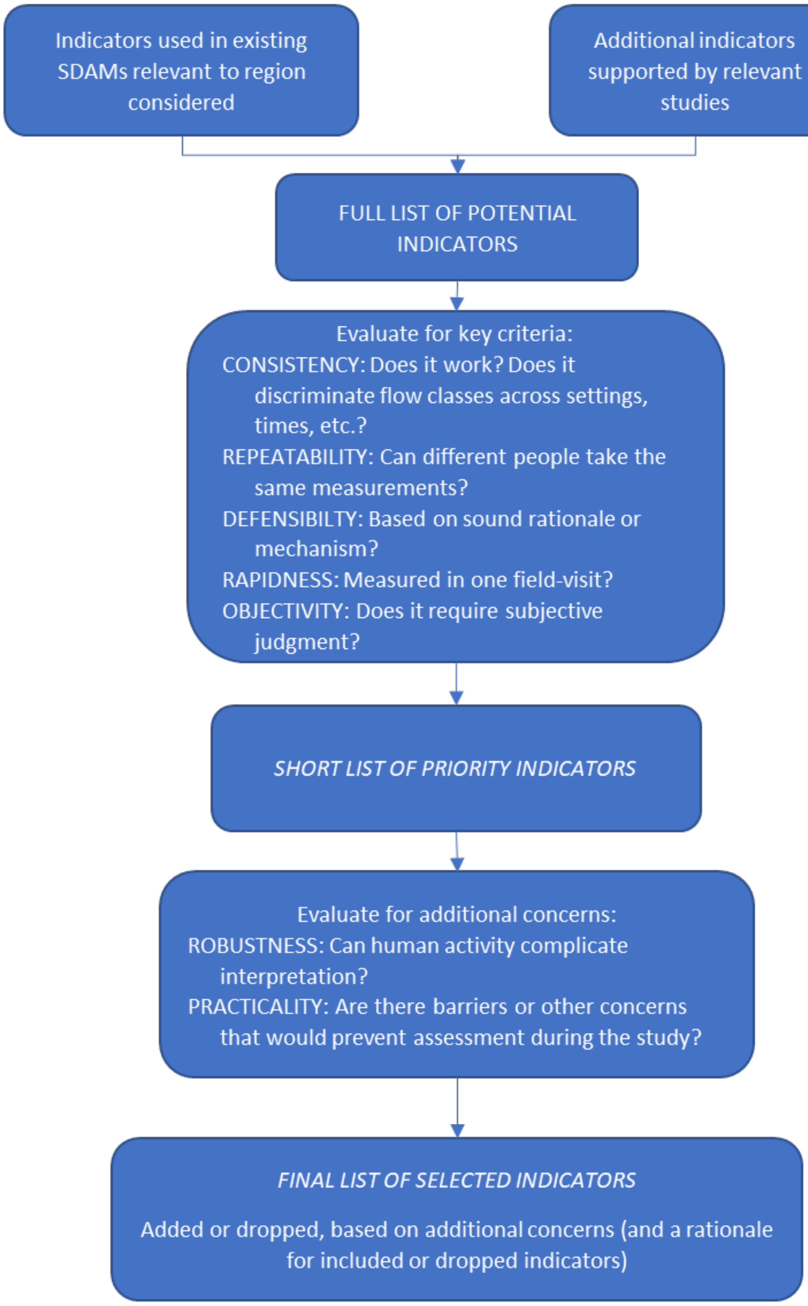

Figure 2. Process for identifying field indicators of flow duration to assess in the AW, WM, and GP.

2.2 Search methods

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

Next, to compile a more thorough collection of GP-specific flow duration sources, additional searches of reference libraries and using search engines, including Google, Google Scholar and Web of Science (WOS), were completed. Dates of search, search terms and combinations, and number of hits for each are shown in Table 1. If the number of hits was large, only the titles or abstracts of the first 50 search results were reviewed to determine applicability to the subject and the GP. This compiled library of sources was also supplemented by appropriate sources from the personal libraries of the technical team.

Table 1. Search parameters and dates used to assemble literature on indicators of flow duration in the Great Plains

Search Source	Search Date	Key Terms	Hits
WOS	12/2/19	“great plains” AND “flow duration”	19
WOS	12/2/19	“prairie” AND “flow duration”	4
WOS	12/2/19	"great plains" 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")	85
WOS	12/2/19	"prairie" 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")	43
WOS	12/2/19	("Montana" OR "North Dakota" OR "South Dakota" OR "Minnesota" OR "Wisconsin" OR "Illinois" OR "Iowa" OR "Kansas" OR "Nebraska" OR "Wyoming" OR "Oklahoma" OR "Missouri" OR "Texas" OR "New Mexico") 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")	237
WOS	12/5/19	"great plains" AND ("macroinvertebrates" OR "amphibians") AND "stream"	118
GS	12/4/19	“great plains” AND “flow duration”	325
GS	12/4/19	"great plains" stream indicator AND "flow duration"	496
GS	12/4/19	“great plains” AND “intermittent stream”	1,430

Search Source	Search Date	Key Terms	Hits
GS	12/4/19	“great plains” AND “perennial stream”	962
GS	12/4/19	“great plains” AND “ephemeral stream”	945
GS	12/4/19	"great plains" AND "flow duration" AND ("macrophytes" OR "algae" OR "bryophytes" OR “riparian vegetation”)	428
GS	12/5/19	"great plains" AND "flow duration" AND ("macroinvertebrates" OR "fish" OR "amphibians")	436
GS	12/6/19	"great plains" AND "hydrologic regime"	1,780
Google	12/30/2019	“Intermittent stream” AND “indicator” AND “Great Plains”	5,340
Google	12/31/2019	“great plains” AND “flow duration”	17,600
Google	12/31/2019	“great plains” AND “streamflow duration” AND “indicator”	293

2.3 Analysis of sources

2.3.1 Including Sources in the Review

Applicability/Utility: Sources with available articles were first reviewed to determine if a source was ‘applicable’ for this analysis. Applicable sources were those that provided information about the biological, physical, or hydrologic characteristics of streams along a flow duration gradient in the GP. Sources in regions outside the GP were also considered applicable if other elements of the reference were relevant to the study. Several sources found during searches did not meet this criterion. Factors that limited the applicability of a citation include reliance on intensive hydrologic data (e.g., continuous flow 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 source was considered applicable, it was evaluated for inclusion in this review following the decision tree in Figure 3 and as described below.

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

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

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

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

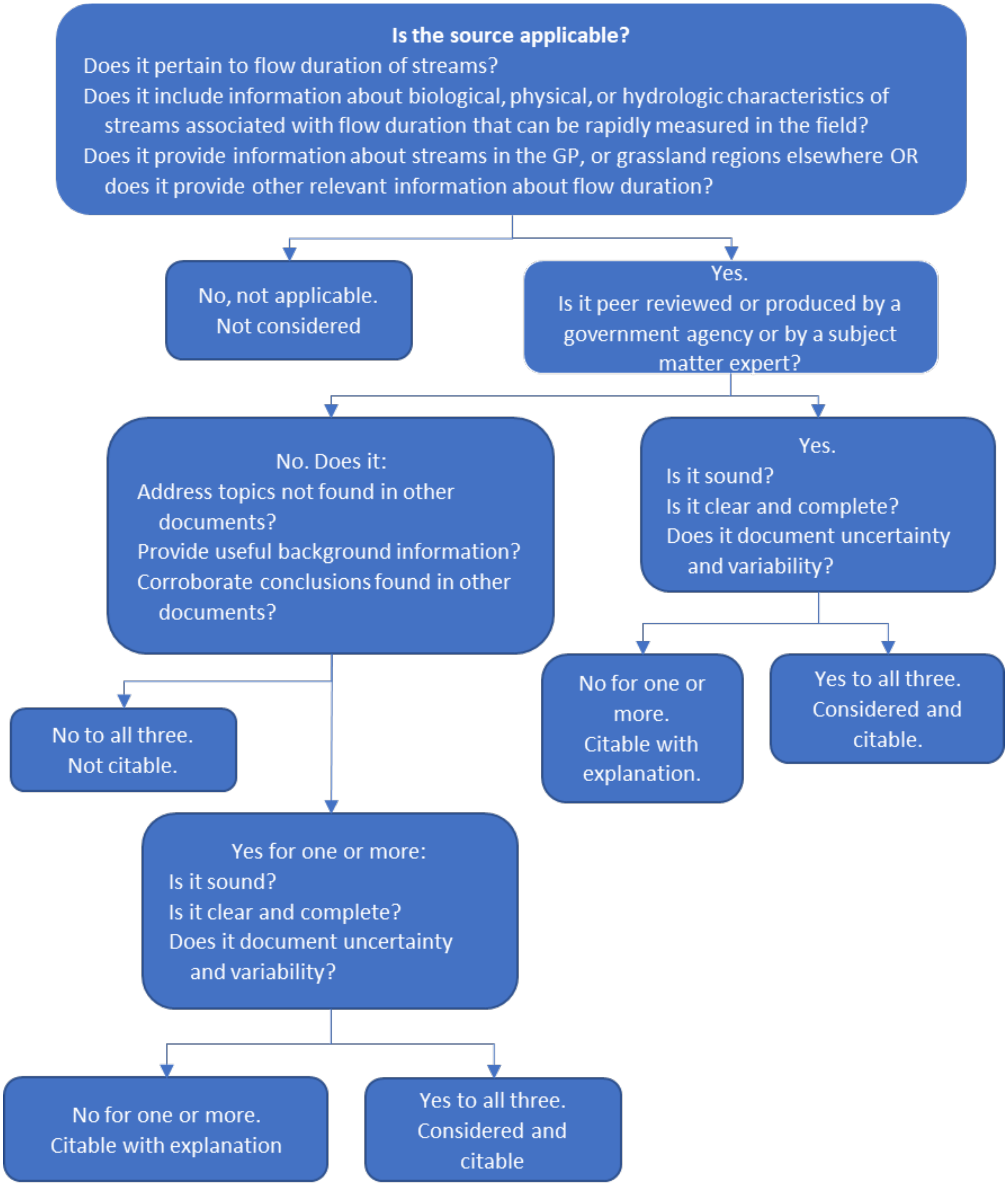

Figure 3. Decision tree for reviewing sources.

2.3.2 Evaluating information about indicators

Each source was reviewed to identify information about indicators of flow duration. First, the flow duration classes represented in the study were determined. Classes were either reported by the authors using their criteria to determine the flow class, or it was determined from other data presented in the study if not given. 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 or had water only in pools, but the duration of the dry period was unclear, the site was classified as “ephemeral or intermittent.” Results, including manuscript text, figures, and tables, were reviewed for information about indicators associated with different site classes. Typical levels (e.g., means) and associated measures of variability (e.g., ranges, standard deviations) were recorded for each indicator.

3.0 EXISTING FLOW DURATION ASSESSMENT METHODS

Thirteen total methods were found to be appropriate for potentially evaluating stream flow duration classes, as they incorporate indirect indicators of flow duration that can be rapidly assessed in the field (Table 2), though only two of these are specifically designed for use in portions of the GP. Table 3 provides a summary of which indicators are used by each method. An additional six methods were found during the AW and WM literature searches (Kennard et al. 2010, Trubilowicz et al. 2013, Berkowitz et al. 2011, Noble et al. 2010, Berhanu et al. 2015, Porras and Scoggins 2013), but were excluded from consideration because they lack a rapid field component, focusing instead on long-term records of measured or modeled flow.

Table 4 provides a summary of the evaluation criteria (see Section 2.1) applied to indicators. Indicators that met all criteria were designated as priority indicators. All priority indicators were proposed for inclusion in the pilot study in the GP. In addition, certain non-priority indicators used in the New Mexico method are also proposed for use in the GP since this method covers portions of this region.

Table 2. Methods for assessing stream flow duration and their associated indicators. Asterisks indicate the protocol covers portions of the Great Plains.

Source	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
Mazor et al. (2021a)	Arid West (parts of AZ, CA, CO, NM, NV, TX, UT, and WY)	Currently in beta testing; intended to be used by the Corps and EPA to support evidence of WOTUS jurisdiction once final	Perennial, intermittent, at least intermittent, and ephemeral	Wetland (hydrophytic) plants, aquatic macroinvertebrates (# and EPT), algae (presence and % cover), fish Supplemental info (for 'needs more information'): amphibians/snakes, perennial indicator macroinvertebrate taxa, iron-oxidizing fungi/bacteria		
Mazor et al. (2021b)	Western Mountains (parts of AZ, CA, CO, MT, NM, SD, UT, and WY)	Currently in beta testing; intended to be used by the Corps and EPA to support evidence of WOTUS jurisdiction once final	Perennial, intermittent, at least intermittent, and ephemeral	Aquatic macroinvertebrates (abundance and richness, includes perennial indicator taxa), algal cover, fish abundance and presence, differences in vegetation Supplemental info (not used in model): presence of aquatic or semi-aquatic amphibians and reptiles, iron-oxidizing fungi/bacteria	Bankfull width, sinuosity	Long-term precipitation, long-term maximum air temperature, snow influence (stratifies what indicators are used in the model and how they are interpreted)
Surface Water Quality Bureau, NM Environment Department (2011)	New Mexico, USA*	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	Ephemeral, perennial and intermittent	Fish, benthic macroinvertebrates, filamentous algae and periphyton, riparian vegetation, rooted upland plants in streambed, iron oxidizing bacteria/fungi, bivalves, amphibians	Sinuosity, floodplain and channel dimensions, channel structure, particle size or stream substrate sorting	Water in channel, hydric soils, sediment on plants or debris, hyporheic zone/groundwater table, seeps/springs

Source	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
Fritz et al. (2006)	Temperate USA (Indiana, Kentucky, Ohio, Illinois, New Hampshire, New York, Vermont, West Virginia, and Washington)*	No	Ephemeral, perennial and intermittent	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
Nadeau (2015a)	Pacific Northwest, USA	Yes; used by Corps Districts and EPA as supporting evidence of Waters of the US (WOTUS) jurisdiction	Ephemeral, perennial and intermittent	Benthic macroinvertebrates, wetland plants, riparian corridor, fish, amphibians/snakes	Slope, evidence of erosion/deposition, floodplain connectivity	
Topping et al. (2009)	Oregon, USA	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	Ephemeral, perennial and Intermittent	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
NC Division of Water Quality (2010)	North Carolina, USA	Yes, to comply with 401 ('waters of the state') and state-level rules (riparian buffers); used by Corps Wilmington District as supporting evidence of WOTUS jurisdiction	Ephemeral, perennial, and intermittent	Fibrous roots in streambed, rooted upland plants, benthic macroinvertebrates, aquatic mollusks, fish, crayfish, amphibians, algae, wetland plants in streambed	Presence of modification/ditches, channel and bank continuity, sinuosity, 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
Svec et al. (2005)	Eastern Kentucky	No	Ephemeral, intermittent, perennial		Bankfull width, width to depth ratio, entrenchment ratio, slope, watershed area	

Source	Geographic location	Used in Regulatory Decision-making?	Represented classes	Biological Indicators	Geomorphological Indicators	Hydrological/Other Indicators
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	Ephemeral, intermittent/perennial (warm water), perennial (cold water)	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
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
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, organic bridges[1], bankfull width, undercut width, particle size/substrate sorting, riffle-pool sequence	Water in channel
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		

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[1] Created when roots extend across, or large woody debris falls over a channel, thus allowing the forest floor to extend across the channel while the streambed remains continuous beneath the bridge.

Table 3. Summary of indicators included in streamflow duration assessment methods from Table 2. Highlighted columns are those existing SDAMs developed for use in the GP region.

Indicator	Arid West (beta)	Western Mountains (beta)	New Mexico (Phase 1)	New Mexico (Phase 2)	Temperate USA	Pacific Northwest	Oregon (Interim)	North Carolina	Kentucky	Ohio	Idaho	Alberta (Foothills)	Mediterranean	Czech Republic
Geomorphology														
Bankfull width and/or depth		X			X				X	X		X		
Continuous bed and banks presence							X	X				X		
Undercut width												X		
Depositional or erosional features in the channel							X	X						
Depositional or erosional features on the floodplain								X						
Distinct substrate composition in streambed from adjacent uplands (particle size or substrate sorting)			X		X		X	X			X	X		
Entrenchment ratio (floodplain/channel dimension)			X		X				X					
Evidence of active floodplain														
Evidence of relict floodplain								X						
Presence of natural grade control							X	X						
Natural valley presence								X						
Presence of headcuts					X		X	X				X		
In-channel sequences of erosional and depositional features			X		X		X	X			X	X		
Stream order								X			X			
Sinuosity		X	X		X		X	X		X				
Slope/Gradient					X	X			X	X	X	X		
Organic bridge												X		
Hydrology														
Continuous logged data				X	X									
Groundwater observation			X		X		X	X		X				
Distribution/presence of leaf litter/packs or debris					X		X	X		X				
Hydric soils or redoximorphic features			X				X							
Modeled hydrology													X	
Observed aquatic state			X		X								X	
Reported aquatic state from interviews													X	
Observed or reported soil saturation			X		X		X			X			X	
Observation of baseflow				X				X		X	X	X	X	
Presence of wrack or drift lines							X	X						

Indicator	Arid West (beta)	Western Mountains (beta)	New Mexico (Phase 1)	New Mexico (Phase 2)	Temperate USA	Pacific Northwest	Oregon (Interim)	North Carolina	Kentucky	Ohio	Idaho	Alberta (Foothills)	Mediterranean	Czech Republic
Sediment deposition on plants or debris			X					X						
Soil-based evidence of a high-water table								X						
Presence of seeps and springs			X				X				X			
Iron-oxidizing bacteria or fungi[1]	X		X				X	X						
Velocity					X									
Biology														
Algae (includes live or dead algal mats/periphyton)	X	X	X	X	X		X	X			X			
Lichens or lichen line							X[3]				X			
Bryophytes					X		X				X			
Fibrous roots in streambed							X	X						
Wetland or aquatic vegetation in channel/ immediate vicinity	X					X	X	X			X	X		
Upland vegetation in channel			X				X	X				X		
Distinct riparian corridor/differences in vegetation		X	X				X[3]							
Aquatic macroinvertebrates - Presence	X	X	X		X	X	X			X				
Aquatic macroinvertebrates - Abundance	X	X		X	X	X		X		X				X
Aquatic macroinvertebrates - Indicator taxa[2]	X	X		X		X	X	X		X	X			X
Aquatic macroinvertebrates – Traits														X
Amphibians – Presence or Indicator Taxa		X		X	X	X	X			X	X			
Amphibians - Abundance and diversity					X			X		X				
Aquatic mollusks/bivalves – Presence/Ease of Detection and/or Abundance								X						
Reptiles – Presence or Indicator Taxa	X	X				X	X							
Fish – Abundance		X		X				X		X				
Fish – Presence	X	X	X			X	X							
Fish –Indicator Taxa											X			
Climate[4]														
Long-term precipitation		X												
Long-term maximum annual air temperature		X												
Snow influence (used for stratification)		X												

[1] This indicator is included in the biological category in the Oregon Interim Method but is considered a hydrologic indicator in the North Carolina method and is categorized as a supplemental indicator (non-categorized) in the New Mexico Phase 1 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] Includes aquatic insects as well as aquatic mollusks (snails and mussels)

[3] Only used in arid and/or alpine areas for this method

[4] Not tested as field indicators but included in analysis as one of a battery of potential climactic indicators.

Table 4. Evaluation criteria for indicators identified in the literature review.

Indicator	Consistency	Repeatability	Defensibility	Rapidness	Objectivity	**Priority Indicator**		Robustness	Practicality	**Proposed**
Geomorphology										
Bankfull width and depth	X	X		X	X	No		X	X	**No**
Continuous bed and banks presence	X	X		X		No		X	X	**No**
Undercut width		X		X	X	No		X	X	**No**
Depositional or erosional features in the channel	X	X		X		No			X	**No**
Depositional or erosional features on the floodplain	X	X		X		No			X	**No**
Distinct substrate composition in streambed from adjacent uplands (particle size or substrate sorting)	X	X		X		No		X	X	**Yes**[1]
Entrenchment ratio (floodplain/channel dimension)	X	X		X	X	No			X	**Yes**[1]
Evidence of active floodplain		X		X		No		X	X	**No**
Evidence of relict floodplain		X		X		No		X	X	**No**
Presence of natural grade control	X	X		X		No			X	**No**
Natural valley presence		X		X		No			X	**No**
Presence of headcuts	X	X		X	X	No		X	X	**No**
In-channel sequences of erosional and depositional features	X	X		X		No		X	X	**Yes**[1]
Stream order		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**
Hydrology										
Continuous logged data	X	X	X		X	No		X		**No**
Groundwater observation	X	X	X		X	No		X		**No**
Distribution/amount of leaf litter or debris	X	X		X		No			X	**No**
Hydric soils or redoximorphic features	X	X	X	X	X	Yes		X	X	**Yes**
Modeled hydrology	X	X	X		X	No		X		**No**
Observed aquatic state	X	X	X	X	X	Yes			X	**Yes**
Reported aquatic state from interviews		X	X		X	No		X		**No**
Observed or reported soil saturation		X	X	X	X	No			X	**No**
Observation of baseflow	X	X	X	X		No		X		**No**
Presence of wrack or drift lines	X	X		X		No			X	**No**
Sediment deposition on plants or debris	X	X		X	X	Yes		X	X	**Yes**[1]
Soil-based evidence of a high-water table	X	X	X	X		No		X	X	**No**
Presence of seeps and springs	X	X	X	X	X	Yes		X	X	**Yes**

Indicator	Consistency	Repeatability	Defensibility	Rapidness	Objectivity	**Priority Indicator**		Robustness	Practicality	**Proposed**
Iron-oxidizing bacteria or fungi	X	X	X	X	X	Yes		X	X	**Yes**
Velocity		X		X	X	No		X	X	**No**
Biology										
Algae	X	X	X	X	X	Yes			X	**Yes**
Lichens		X	X	X	X	No			X	**No**
Bryophytes	X	X	X	X	X	Yes			X	**Yes**
Fibrous roots in streambed	X	X		X		No			X	**No**
Wetland vegetation (FACW, OBL, SAV)	X	X	X	X	X	Yes			X	**Yes**
Upland vegetation in channel	X	X	X	X	X	Yes			X	**Yes**
Riparian vegetation	X	X	X	X	X	Yes			X	**Yes**
Aquatic macroinvertebrates - Presence	X	X	X	X	X	Yes		X	X	**Yes**
Aquatic macroinvertebrates - Abundance	X	X	X	X	X	Yes		X	X	**Yes**
Aquatic macroinvertebrates - Indicator taxa	X	X	X	X	X	Yes			X	**Yes**
Aquatic macroinvertebrates – Traits	X	X			X	No		X	X	No
Amphibians - Presence	X	X	X	X	X	Yes			X	**Yes**
Amphibians - Abundance and diversity	X	X	X		X	No				**No**
Aquatic mollusks -- Presence	X	X	X	X	X	Yes		X	X	**Yes**
Reptiles - Presence	X	X	X	X	X	Yes			X	**Yes**
Fish - Abundance	X	X	X		X	No				**No**
Fish - Presence	X	X	X	X	X	Yes			X	**Yes**
Fish – Indicator taxa		X	X		X	No				**No**
Additional indicators from primary literature										
Geomorphology										
Max pool depth*		X		X	X	No		X	X	**No**
Hydrology										
Dissolved O_2 *		X		X	X	No			X	**No**
Water column organic C[+]		X		X	X	No			X	**No**
Woody jams[§]		X	X	X	X	No		X	X	**No**
Biology										
Diatom abundance[+]		X			X	No				**No**
Bird abundance[+]		X			X	No				**No**
Terrestrial arthropods[+]		X	X	X	X	No				**No**
Canopy cover[+]	X	X		X	X	No			X	**No**
Riparian vegetation – diversity[+]	X	X	X		X	No				**No**
Microbial diversity[+]		X	X		X	No				**No**

[1]: Non-priority indicator proposed for inclusion because it is required by the New Mexico protocol (NMED 2011)

* Identified in both AW and WM literature reviews

\+ Identified in AW literature review

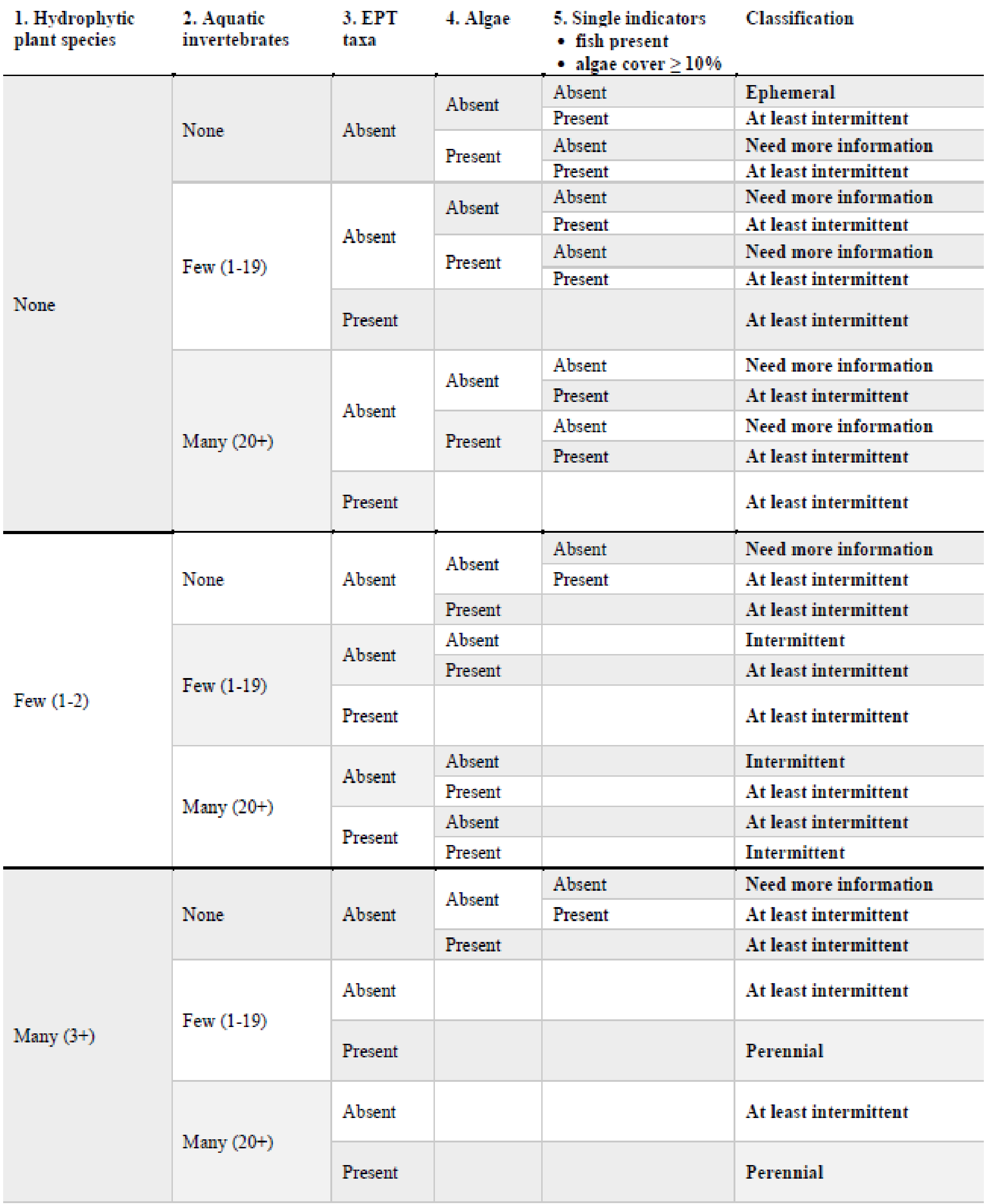
§ Identified in WM literature review

3.1 Arid West (Beta)

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

1) How many hydrophytic plant species are growing in the channel, or within one half-channel width of the channel?
2) How many aquatic macroinvertebrate individuals are found?
3) Is there evidence of aquatic stages of EPT taxa?
4) Are algae found on the streambed?
5) Are single indicators (i.e., the presence of fish or ≥10% algal cover) of intermittent or perennial streamflow duration observed?

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



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

Figure 4: Streamflow classifications based on field-measured indicator data in the beta SDAM for the Arid West (Mazor et al. 2021a)

3.2 Western Mountains (Beta)

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

Field Indicators

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

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

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

The presence of fish may also be used as a single indicator to classify a stream as "at least intermittent" even if other indicators suggest an ephemeral classification. This method is stratified by snow-influence, as shown in Figure 5.

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

Figure 5: Field-measured and desktop indicator data used in the beta SDAM for the Western Mountains based on snow-influence (Mazor et al. 2021b).

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

3.3 New Mexico

The New Mexico Environment Department developed a two-level method for assessing flow duration (NM Environment Department 2011) for streams throughout the state, including the small portion that lies within the Great Plains region as defined in this analysis. The first level (Level 1) is more rapid and is sometimes sufficient to classify a stream as perennial, intermittent, or ephemeral. Level 1 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 level (Level 2) consisting of quantitative fish and benthic macroinvertebrate samples may be necessary. Level 2 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 index that forms the basis of the classification (Table 5). Notably, this method may result in ambiguous situations (gray rows in Table 5), which may be resolved by the 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. Like Nadeau (2015), this method was also designed for application in semi-arid regions. Like Topping et al. (2009), many indicators require subjective visual assessment by practitioners.

Table 5. Score interpretation for the New Mexico flow duration 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 (Level 2) 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 (Level 2) indicates that the stream is intermittent
Perennial	Greater than 22.0	Stream is perennial

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

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

3.5 Pacific Northwest

For purposes of classifying perennial, intermittent and ephemeral streams in the Pacific Northwest (PNW), Nadeau (2015) developed a method that uses five biological and physical habitat indicators: 1) presence of aquatic macroinvertebrates; 2) number of mayflies (order Ephemeroptera); 3) presence of perennial indicator taxa from Mazzacano and Black (2008) or Blackburn (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 6), and not all indicators are needed to make a determination at every site. Consequently, it is among the simplest tools to implement. This method strongly emphasizes biological indicators, including only one geomorphological indicator (i.e., slope), and no hydrological indicators.

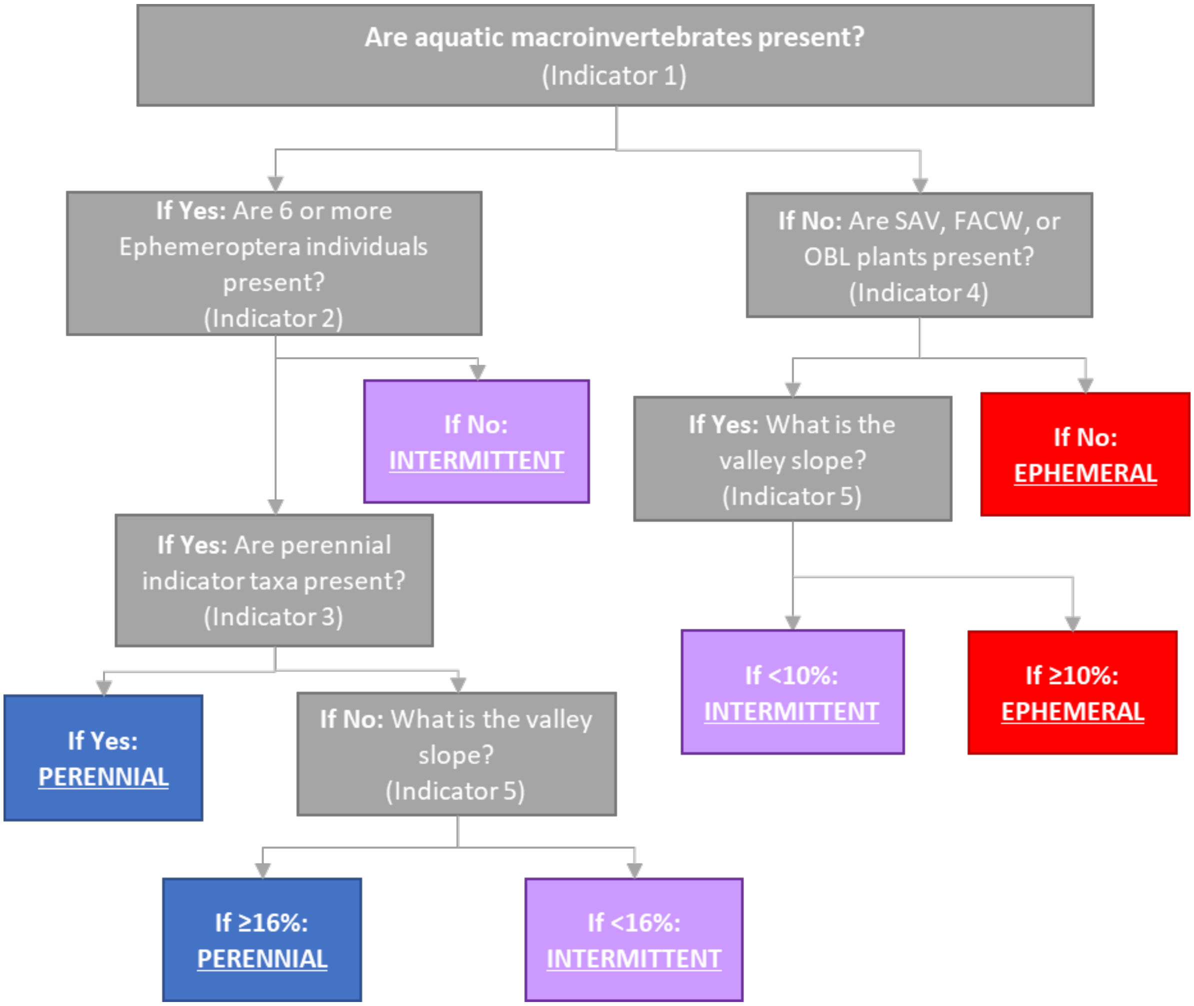


Figure 6. Flowchart used to determine stream flow class in the Pacific Northwest method (adapted from Nadeau 2015).

3.6 Interim Oregon Method

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

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

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

3.7 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. As with the New Mexico method, indicators are scored to yield an index, with more indicators (or more robustly evident indicators) yielding a higher score; similarly, the presence of specific taxa (fish, crayfish, amphibians, or clams) can result in a perennial designation, even if scores are low. Scores required for perennial or intermittent designations are somewhat higher for the North Carolina method than the New Mexico method, perhaps due to the higher number of indicators (26 vs. 14). This method was developed for a region that generally receives at least 5-10 more inches of annual rainfall (excluding far southwestern NC, where rainfall totals are much higher) than the wettest parts of the GP and about 4 times more annual rainfall than the driest parts of the GP.

3.8 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.

3.9 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 are less than 40cm) 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 7. 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.

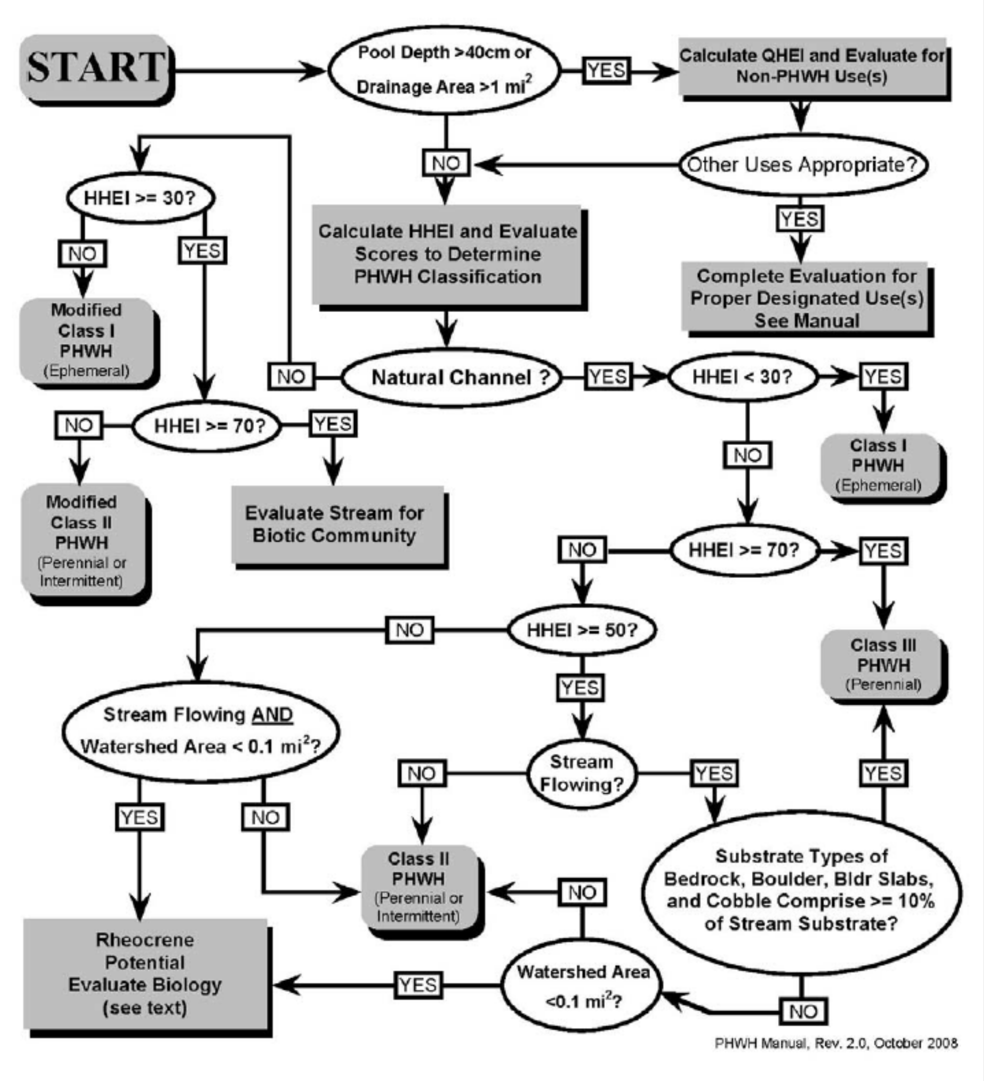


Figure 7. PHWH stream classification flow chart based on HHEI scoring (from Ohio EPA 2012)

3.10 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 (just 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 assessment method.

3.11 Alberta, Canada (Foothills)

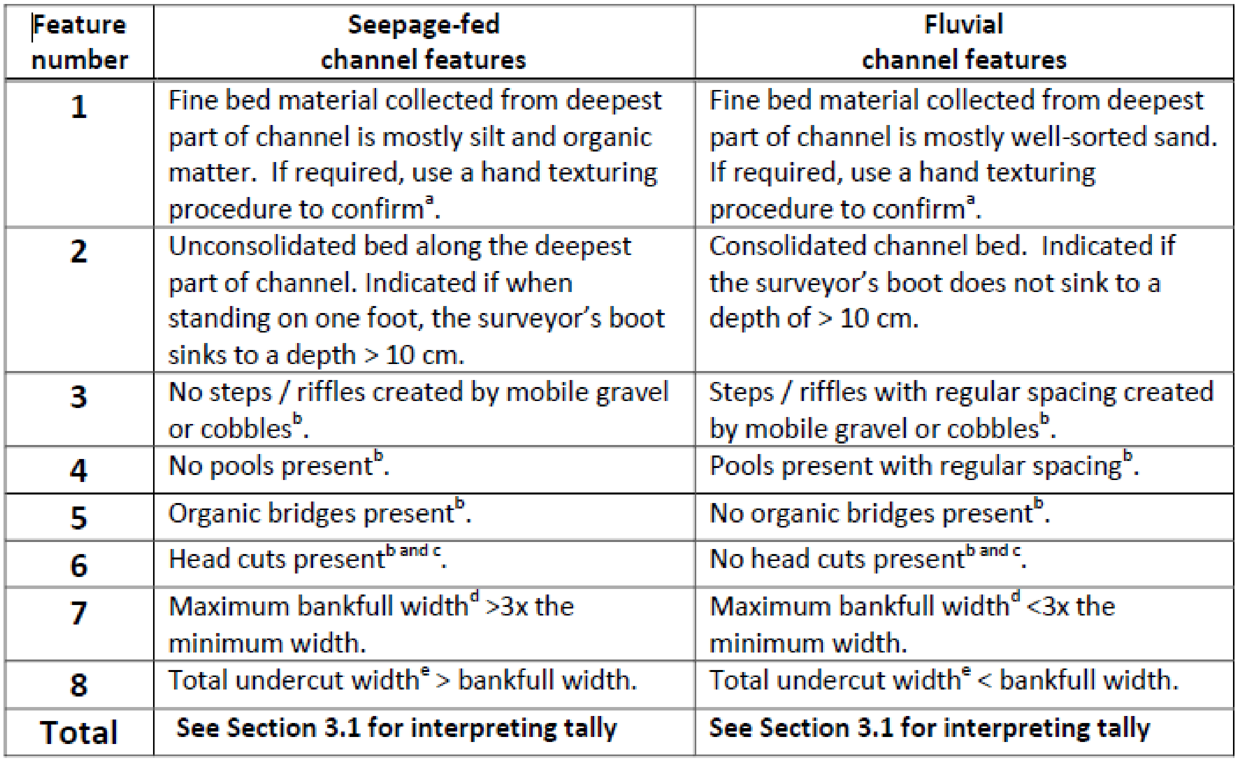
This method was developed for use in the forested Foothills region of Alberta to assign erosion-based stream classifications to headwater streams to better inform forest management decisions (McCleary et al. 2012). These classifications are largely based on dominant surface erosion processes, which are 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 2 stream classes (not including upland) from each other and seepage-fed and fluvial channels. For seepage and fluvial channels, the indicators shown in Figure 8 are used to determine the class. This method is a simple way to distinguish epehemeral 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 8. Characteristics of seepage-fed and fluvial channels in McCleary et al. (2012)

3.12 Mediterranean Europe

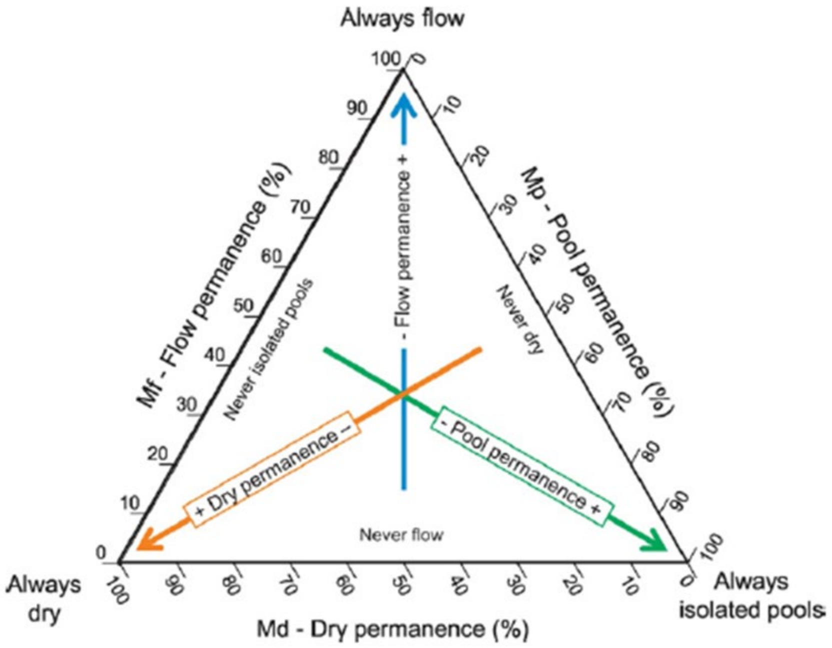
Prat et al. (2014) developed an assessment framework known as Mediterranean Intermittent River ManAGEment (MIRAGE) to identify the flow status of streams in order to guide selection of appropriate condition assessment tools based on biology, water chemistry, habitat, or other condition indicators. The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

Interview methodology 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 (Md) in Figure 9. Using this plot, further flow regime classifications (e.g., fluent-stagnant, quasi-perennial, episodic) are then defined.



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

3.13 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 7). Based on a data set of 23 streams in the Czech Republic (mostly in the Carpathian Mountains and Central Highlands) consisting mostly of paired perennial and non-perennial sites (both “intermittent” and “near perennial”), they identified indicator species associated with different flow regimes, and developed a seasonally-adjusted index consisting of three metrics that could discriminate between the three flow-regime classes (Table 7).

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

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

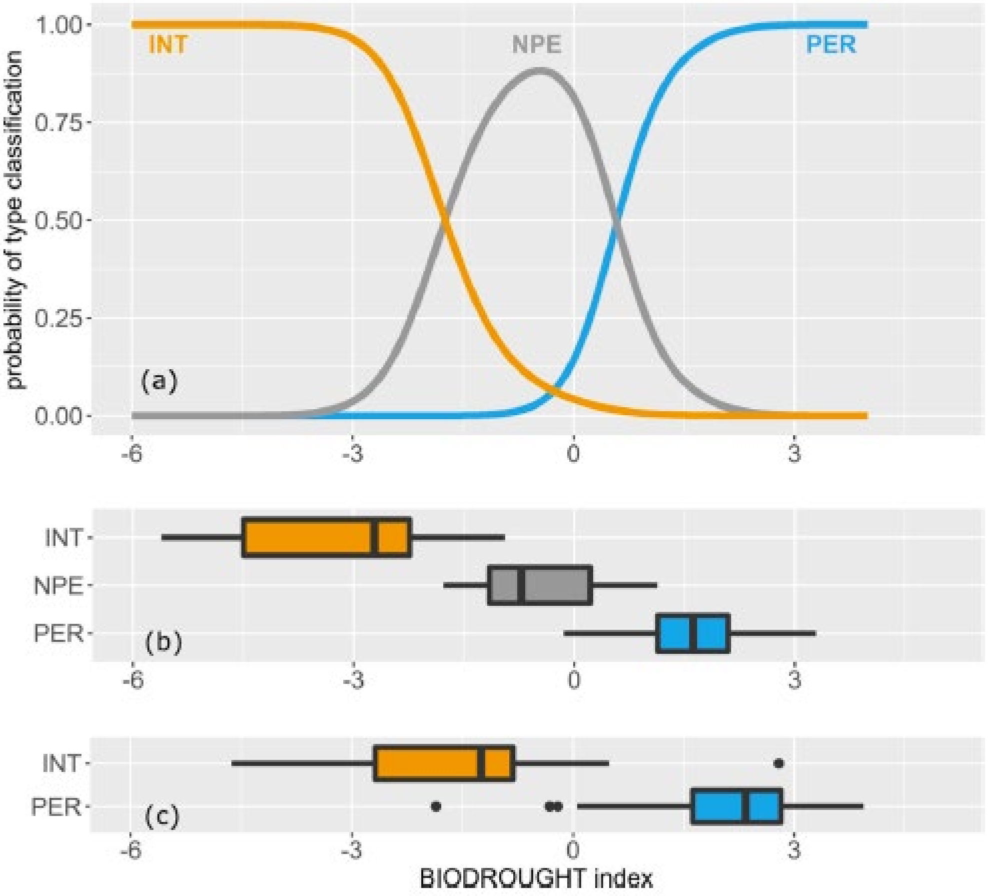


Figure 10. Relationship between biodrought index scores and flow classes, from Straka et al. (2019). Top panel shows the probability of classification as the index score increases. The second panel shows scores associated with calibration data. The bottom panel shows scores associated with independent 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). 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. This index has not been validated in the field.

4.0 INDICATORS IN THE GREAT PLAINS

A review of literature describing indicators in the GP shows general support for indicators used in current flow duration assessment methods, particularly biological indicators. A discussion of each class of indicators and evidence for their association with streamflow classes in the GP is given below.

4.1 Geomorphological Indicators

Aside from New Mexico Level I indicators that assess geomorphology, there were no studies or other methods found that defined differences in stream geomorphology based on flow duration classification in the GP. Instead, relevant studies described the characteristics of GP streams with known flow duration and/or substrate types. Costigan et al. (2014) found that for a large, perennial sand-bed stream in south-central Kansas (Ninnescah River), bed slope and sinuosity decreased, and bankfull width to depth ratios increased, as the channel progressed downstream. Friedman and Lee (2002) found that ephemeral sand-bed channels in the Colorado piedmont widen and narrow in response to flooding and periods of low-flow respectively. Channel narrowing was also accompanied by an increase in forest width of a similar magnitude, as trees (primarily cottonwoods) became established in the channel bed during these periods of low flow. In a preliminary analysis of potential controls on refuge pools (those that retain water throughout the year, but are often isolated for long periods), Wohl et al. (2009) describe typical ephemeral and intermittent channels found on the Pawnee National Grassland (northeast CO) as grassy swales with relatively broad, shallow active channels, highly variable degrees of longitudinal incision, and active headcuts throughout.

<u>Tufa Deposits</u>

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

4.2 Hydrologic Indicators

Several methods identified in this review use the prevalence and/or distribution of leaf litter/packs or wrack lines (e.g., Topping et al. 2009, NCDWQ 2010) to distinguish between flow duration types. For leaf litter, the interim Oregon and North Carolina methods assign scores for this indicator based on the assumption that more leaf litter will be retained in ephemeral and intermittent channels due to prolonged absences of flow that might move leaf debris out of a reach. The North Carolina method was developed for a largely forested ecoregion while the interim Oregon method was developed for a region that encompasses both forests and arid grasslands.

In grassland dominated areas of the GP, allochthonous organic matter inputs are expected to be lower than in forested systems, especially in ephemeral headwater reaches that may lack a riparian gallery forest. In addition, prairie streams tend to retain less of this material because of frequent scouring floods and a lack of retentive structures such as large wood (Gurtz et al. 1988). However, two studies identified in this review compared the decomposition rates of leaf packs in intermittent and perennial streams within the GP: in north-central Texas (Hill et al. 1988) and northeastern Kansas (Tate and Gurtz 1986). Both studies found that decomposition rates of hardwood leaf litter (e.g., elm, box elder, pecan) were slower in intermittent channels versus perennial channels; therefore, leaf litter might be expected to persist longer in those environments, due not just to absence of flow but potential differences in decay rates.

Dry conditions hinder both microbial growth and macroinvertebrate re-colonization times, which likely impact decomposition processes. However, Tate and Gurtz (1986) found a low prevalence of macroinvertebrate shredders, which are considered an important factor in detritus processing, in both intermittent and perennial channels. This outcome suggests that their absence did not play a crucial role in decay rate differences, at least in this study. It is important to note that the use of this indicator in grassland dominated areas of the GP may be confounded by a lack of woody vegetation (at least for headwaters higher in the drainage network) and the characteristic high intensity flooding events typical of this region.

Woody jams

In the Western Mountains (WM) literature review, large woody jams (also called "debris jams") are identified as a potentially important component of streams in the WM (e.g. Mersel and Lichvar 2014; Faustini and Jones 2003, Abbe and Montgomery 1996). In addition, most of the studies in Mersel and Lichvar (2014) investigating the impacts of large woody jams on stream ecology, stream channel morphology, water velocity, and to a lesser extent, flow duration, are from more heavily forested regions largely in the Pacific Northwest. No studies on the importance of woody jams (for flow duration or otherwise) in the GP were found during the literature review.

4.3 Biological Indicators

In contrast to many of the other indicators mentioned above, biological indicators are often directly related to flow duration. Consequently, many studies corroborated relationships between biological indicators and flow duration, particularly aquatic macroinvertebrates and plants. Also included here are discussions of studies from the Arid West (AW) and Western Mountains (WM) since biological indicators can be widespread; if a study is specific to the Great Plains (GP), it is indicated as such.

4.3.1 Aquatic macroinvertebrates

In general, studies provide strong support for the use of aquatic invertebrates as indicators of flow duration. Although training is required, field-based family level identifications are practical for aquatic macroinvertebrates, further underscoring their suitability as indicators. The Pacific Northwest method (Nadeau 2015) makes use of studies by the Xerces society (i.e., Mazzacano and Black 2008, Blackburn and Mazzacano 2012) to identify perennial indicator taxa in the Pacfic Northwest and many of these taxa, where present, may have similar indicator values in the GP (see below).

In addition, studies conducted in the GP that compared or characterized community composition and/or abundance of macroinvertebrates in perennial streams and streams with shorter flow durations were found during this literature review and are summarized in Table 8. Study results are presented at different taxonomic resolutions, ranging from genus and species to family level or higher. Provided flow classifications are also of varying levels of specificity, with streams having shorter than perennial flow duration often not categorized into intermittent or ephemeral classes.

Table 8. GP studies of aquatic macroinvertebrates in different flow duration classes.

Source	Region	Notes	Perennial	Intermittent/ Ephemeral
Bovbjerg et al. (1970)	Upper Little Sioux River in Minnesota and Iowa	Sampled aquatic fauna in intermittent and perennial sections of the river	Associated taxa: All unionid mussels and *Sphaerium* sp., *Ferrissia, Callibaetus, Caenis, Isonychia, Ameletus, Ancyronyx, Ischnura*, and *Orconectes virilis*	Associated taxa: *Stagnicola reflexa*, *Planorbula*, *Peltodytes, Pelonomus*, and *Notonecta*
Bramblett and Fausch (1991)	Southeastern Colorado – Purgatoire River and 10 tributaries	Habitat and biota descriptions; tributaries not given a definitive flow classification	Associated taxa (Purgatoire River): *Choroterpes mexicanus, Microcylloepus, Cheumatopsyche, Hydropsyche,* Simuliidae; mostly collector-gatherers and filterers	The tributaries had a greater preponderance of predators (odonates) and scrapers (physid snails)

Source	Region	Notes	Perennial	Intermittent/ Ephemeral
Buchholtz and Buchholtz (1974)	Southeast South Dakota (Vermilion River)	Sampled aquatic fauna in intermittent and perennial ('continous') sections of the river	Associated taxa: *Ischnura, Leucorrhinia, Trichocorixa, Agabus, Enallagma, Ranatra*, and *Laccophilinae*	Associated taxa: *Ferrissia, Suphisellus*
Burk and Kennedy (2013)	North-central Texas (Ash Creek [spring fed] and tributaries)	Evaluated perennial riffles and pools, and disconnected pools (shaded and non-shaded); except for Ash Creek, no definitive flow classification is given	Associated taxa (perennial riffles): *Chimarra*, *Cheumatopsyche, Similium, Lutrochus, Neotrichia,* and *Mayatrichia*	Found in shaded disconnected pools lacking surface flow for over a month: *Marilia*, *Oecetis*, *Helicopsyche*, and *Microcylloepus*
Fritz and Dodds (2002)	Northeast Kansas (Kings Creek/Konza Prairie	Evaluated role of disturbance (e.g. drying, flood) and refugia on benthic assemblage in intermittent and perennial streams	Associated taxa: *Hydropsyche, Neochoroterpes, Calopteryx maculata, and Argia plana*	Associated taxa: Brachyceran Diptera (Phoridae, Sepsidae, Scathophagidae)
Harrell and Dorris (1968)	North-central Oklahoma (Otter Creek drainage)	Characterized benthic macroinvertebrate community of intermittent streams	Not Applicable (N/A)	Oligochaetes (70%) and dipterans (22%) made up majority of all macrobenthos collected in pools; dipterans (*Pelopia* spp.) replaced *Limnodriulus* spp. as the dominant taxon as water levels receded in summer
Harris et al. (1999)	Nebraska and southwest Minnesota	Characterized benthic macroinvertebrate community in perennial streams	Associated taxa (most abundant): Chironomidae, Simuliidae, Oligochaeta, Nemotoda, *Heptagenia, Leptophlebia, Taniopteryx,* Baetidae, Physidae	N/A
King et al. (2015)	Austin, Texas (urban streams)	Uses Flow Permanence Index (FPI; Porras and Scoggins 2013); ranges from 0 to 100. No estimated score ranges are given for perennial, intermittent, and ephemeral flow	Taxa found only in streams with an FPI of 90 or above: *Heterelmis*, and *Nectopsyche*; others appearing and increasing substantially in number above an FPI of 70 include *Psephenus*, *Isonychia*, *Macrelmis texanus*, and *Erpetogomphus*	*Physella* snails experienced large increases in streams with an FPI of 30 or lower

Source	Region	Notes	Perennial	Intermittent/ Ephemeral
Miller and Golladay (1996)	Southern Oklahoma	Macrobenthos response to flooding events ('spates) in a perennial and intermittent stream	Associated taxa: *Baetis, Chimarra, Leptophlebia, Tricorythodes,* and Tipulidae; Chironomids were most common invert found in both stream types.	Intermittent associated taxa: *Physella, Zealeuctra, Perlesta*, and Perlodidae; large numbers of *Caenis* and Simuliidae, though these taxa were found in both stream types; chironomids were most common invert found in both stream types.
Stagliano (2005)	Missouri River drainage in Montana	Aquatic community classification—includes perennial and intermittent streams in the northern glaciated Plains and northwestern Plains ecoregions	Many species are common between smaller perennial and intermittent streams (including mayflies *Caenis* and *Callibaetis*); however, *Cheumatopsyche, Hydropsyche, Dubiraphia,* and *Microcylloepus* were found only in the perennial streams	Intermittent streams with fishless pools that re-hydrate may be dominated by crustaceans with resting egg stages: Ostracoda, Copepoda, Cladocera, *Branchinecta* (fairy shrimp), *Caenestheriella* (clam shrimp), and *Lepidurus* (tadpole shrimp)
Vander Vorste et al. (2008)	Eastern Montana (northern glaciated Plains)	Characterized benthic macroinvertebrate community of intermittent streams (family level)	N/A	Chironomidae was most prevalent taxa in sampled intermittent streams; in general, collector-gatherers and burrowers were the most common taxa found
Vander Vorste (2010)	South Dakota (northern glaciated Plains)	Characterized benthic macroinvertebrate community of intermittent streams (family level)	N/A	Families found in highest abundance were Chironomidae, Tubificidae, Enchytraeidae, Ceratopogonidae, Culicidae, and Lymnaeidae

Below, major groups of aquatic macroinvertebrates are considered in relation to flow duration; studies are not confined to the GP, but also draw from the AW and WM literature reviews, 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) that has extended its range into parts of the GP. However, Straka et al. (2019) identified this taxon as an indicator of intermittent or nearly perennial Czech streams, along with numerous taxa in Physidae, Planorbiidae, and Lymnaeidae. A number of Lymnaeid taxa were also indicators of perennial flow, along with the Ancylid snail *Ancylus fluviatilis*. However, in the GP, Bovbjerg et al. (1970) found members of Planorbiidae and Lymnaeidae in intermittent reaches of the Little Sioux River. Three studies conducted in the GP also found that Physid snails (mostly *Physella*) were found or were in greater abundance in streams with less than perennial flow (Bramblett and Fausch 1991, King et al. 2015, and Miller and Golladay 1996), though they do not appear to be restricted to streams with shorter flow durations (Stagliano 2005, Harris et al. 1999).

Although they are less widespread than many gastropods, freshwater mussels may be good indicators of perennial flow, though some species in the Unionidae family (widespread in North America) have been shown to survive prolonged periods of drying (Alyakrinskaya 2004). However, Metcalf (1983) also found that a relatively short drought event (1 year) in southeast Kansas resulted in a large die-off of unionid mussels. In addition, in a faunal study of the upper Little Sioux River in Minnesota and Iowa (Bovbjerg et al. 1970), no unionid mussels were found in the intermittent section of the river farthest upstream. Fingernail clams (Sphaeriidae) are not treated as a perennial indicator taxon, but some support for this classification is found in Lusardi et al. (2016) and Bovbjerg et al. (1970). However, Straka (2019) identified *Pisidium* as an indicator of intermittent flow.

Mayflies

No mayfly families are considered to be an indicator of perennial flow in Blackburn and Mazzacano (2012), although studies suggest that some taxa show a preference for perennial flow (e.g., Isonychidae, King et al. 2015, Bovbjerg et al. 1970; Leptophlebiidae, Fritz and Dodds 2002, Miller and Golladay 1996, and Harris et al. 1999). Some studies support Baetidae as a perennial indicator (e.g., Bovbjerg et al. 1970, 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*).

Stoneflies

Several studies support the use of perlid stoneflies as indicators of perennial flow (e.g., Bonada et al. 2006, Lusardi et al. 2016, Bogan 2017), but a few studies report them at very low abundance in intermittent streams (e.g., del Rosario and Resh 2000, Miller and Golladay 1996). Few studies in the AW and WM and no studies in the GP indicated if Pteronarcyidae were collected, suggesting that this taxon may be too rare to be a useful indicator in these regions.

Although Capniidae are listed as an indicator of intermittent flow in Blackburn and Mazzacano (2012), and this family is known to contain intermittent stream specialist taxa (e.g., *Mesocapnia arizonensis,* Bogan 2017), intermittent indicators are not used in Nadeau (2015), and many taxa in this family are found in perennial streams as well as intermittent (Bogan 2017).

In Czech streams, Straka et al. (2019) identified four indicators of intermittent flow (species in Taeniopterygidae, Capniidae, Perlodidae, and Nemouridae), and numerous indicators of perennial flow (species in Nemouridae, Perlidae, Perlodidae, Chloroperlidae, and Leuctridae).

One *Isoperla* species (i.e., *I. tripartita*) is an indicator of intermittent flows, whereas two species (i.e., *I. oxlepis* and *I. rivularum*) are indicators of perennial flows, suggesting that even genus-level identifications may be too coarse to provide meaningful indication of flow duration.

Caddisflies

In the AW and WM, several studies support the use of Hydropsychidae, and to a lesser extent, the other caddisfly families (i.e., Philopotamidae, Rhyacophilidae, and Glossosomatidae) as indicators of perennial flow (Bonada et al. 2006, Miller and Brasher 2011, Erman and Erman 1995). In the GP, five studies support the use of caddisfly species in Hydropsychidae and Philopotamidae as perennial indicators (Bramblett and Fausch 1991, Burk and Kenndedy 2013, Fritz and Dodds 2002, Miller and Golladay 1996, and Stagliano 2005). In parts of the WM, several studies suggested that additional families, such as Brachycentridae or Calamoceratidae, may be good indicators of perennial flow (Bonada et al. 2006, Miller and Brasher 2011). Staka et al. (2019) identified several indicator species for intermittent flows in Czech streams (Beraeidae, Phryganeidae, and numerous species in Limnephilidae), and numerous indicators of perennial flows in several families (including Glossosomatidae, Hydropsychidae, Limnephilidae, Phryganeidae, Polycentropidae, and Rhyacophilidae).

Beetles

Several studies illustrate that elmid beetles show a strong preference for perennial streams, but they are occasionally found in intermittent reaches as well (Burk and Kennedy 2013)—particularly if those reaches are close to perennial waterbodies. De Jong et al. (2013) note that *Optioservus quadrimaculatus* and *Zaitzevia parvula* are comparatively well-adapted to colonize intermittent streams shortly after rewetting in the AW. Psephenidae are supported as an indicator of perennial flow in Bonada et al. (2006) and King et al. (2015). Several aquatic beetle families could be indicators of intermittent flow (e.g., Hydrophilidae: Bonada et al. 2006, Bogan and Lytle 2007), and some are documented from ephemeral streams (De Jong et al. 2015). Straka et al. (2019) identified several indicators of intermittent flow in Czech streams (mostly Dytiscidae, Hydrophilidae, Helophoridae, and Hydraenidae), as well as of perennial streams (several Elimdae, as well as Dytiscidae, Gryinidae, Hydraenidae, and Scirtidae).

Odonata

Several studies support the use of Gomphidae and Cordulegastridae as indicators of perennial flow (e.g., Bonada et al. 2006, King et al. 2015). Straka et al. (2019) identified a Coenagrionidae species to be indicative of intermittent flows in Czech streams; while they found no Odonata taxa to be indicative of perennial flows, Cordulegastrid taxa were excluded from intermittent streams (in agreement with Blackburn and Mazzacano 2012), whereas Calopterygidae were more widespread (in disagreement with Blackburn and Mazzacano 2012). In the GP, Fritz and Dodds (2002), Buchholtz and Buchholtz (1971), and Bovbjerg et al. (1970) found representatives from Calopterygidae (*Calopteryx maculata*) and Coenagrionidae (*Argia plana*, *Enallagma* sp., *Ischnura* sp.) to be associated with perennial streams.

Megaloptera

Corydalidae are listed as an indicator of perennial streams in the PNW (Blackburn and Mazzacano 2012), but some reports from montane regions in the arid southwest (e.g., Bogan and Lytle 2007) considered them to be indicative of intermittent flow. Cover et al. (2015) describes two genus-groups within this family: the *Neohermes-Protochauliodes* group, which is well adapted to intermittency by building hyporheic aestivation chambers to survive the dry period (Figure 11), and the *Orohermes-Dysmicohermes* group, which does not burrow and is therefore restricted to perennial streams. Distinguishing the two genus-groups in the field may be possible, as the *Neohermes-Protochauliodes* group has distinctive head patterns in late instars (M. Cover, personal communication).

Figure 11. Neohermes aestivation chamber in a dry streambed in Arizona; the red box indicates the area shown in the right photo (courtesy M.T. Bogan).

Diptera

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 other studies (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 GP, Chironomidae were one of the most abundant and cosmopolitan taxa in both perennial and intermittent streams (Miller and Golladay 1996, Vander Vorste et al. 2008, Vander Vorste 2010). Fritz and Dodds (2002) also found that families in the Brachycera suborder (Phoridae, Sepsidae, and Scathophagidae) were generally associated with intermittent streams. However, challenges with identifying this group in the field may make them impractical for use in a field-based, rapid 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*. 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 (see Table 6; fairy, clam, and tadpole shrimps, ostracodes, copepods, and cladocerans) have resting egg stages that can resist dry periods for a year or more. However, most of the indicative taxa are small and likely hard to identify easily in the field, though the shrimps may allow for field sampling/identification.

Birnbaum et al. (2007) found that crayfish of the Cambaridae family inhabited intermittent streams in central Texas, even during low to no flow conditions in summer. However, as documented by Bovbjerg (1952; 1970) in northeast Illinois and the Little Sioux River headwaters in Minnesota and Iowa, certain species of Cambaridae such as *Faxonius propinquus* (née *Orconectes propinquus*) and *F. virilis* (née *O. virilis*) are more likely to be found in oxygen rich flowing stream systems and are replaced by other members of the Cambaridae, such as *F. immunis* (née *O. immunis*) and *Fallicambarus fodiens* (née *Cambarus fodiens*), that are better able to withstand lower oxygen levels in slow-moving or pool habitats.

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 after flow onset 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 macroalgal forms may be an effective indicator of flow duration.

Taxonomic identification of most algal species is difficult 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* tends to dominate in perennial streams, while diatoms and the filamentous cyanobacterium *Oscillatoria* dominate in intermittent streams. Certain macroalgal groups are readily identifiable in the field (Entwisle et al. 1997), potentially providing sufficient information to inform flow duration assessment.

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

4.3.3 Bryophytes

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

4.3.4 Riparian and wetland vascular plants

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

Several studies show a very strong relationship between flow duration and plant communities (e.g., Caskey et al. 2015, Stromberg et al. 2007). Caskey et al. (2015) showed a decrease in wetland plant occurance after diversion of perennial flow along stream reaches in the Routt National Forest, CO (within the WM). Reynolds and Shafroth (2017) noted a number of plant species indicative of perennial versus intermittent flow regimes in high and low elevation streams in the Colorado Basin. Although that study did not identify ephemeral streams, the authors report that the driest streams in their study were dominated by upland plants, such as sagebrush and juniper (Lindsay Reyonlds, personal communication). Thus, the taxonomic composition of riparian and wetland plants may be an effective indicator of flow duration. Table 9 shows potential indicator species from these WM studies, included here because some species have distributions that extend into or encompass the GP.

Table 9. Vegetation associated with flow-duration classes.

Source	Region	Notes	Perennial	Intermittent
Caskey et al. (2015)	Colorado Rocky Mtns. – Routt NF	Flow diversion experiment, summarizing vegetation changes above and below diversions	Associated taxa (labeled as obligate wetland species): *Carex utriculata, Mertensia ciliate, Salix planifolia, Salix wolfii, Veronica americana*	
Reynolds and Shafroth (2017)	Upper Colorado River Basin	Characteristic riparian plants associated with high and low elevation perennial and intermittent streams	Associated taxa (low elevation): *Rhus trilobata, Betula occidentalis, Carex nebrascensis, Juncus torreyi, Rosa woodsia, Equisetum arvense*	Associated taxa (low elevation): *Ericameria nauseosa, Atriplex canescens, Sporobolus cryptandrus, Gutierrezia sarothrae*

4.3.5 Vertebrates

Several flow duration assessment methods use the presence of vertebrates as indicators of perennial or intermittent flow. Nadeau (2015), NCDWQ (2010), and Topping et al. (2009) use the presence of fish as a biological flow duration indicator. Generally, the GP is characterized by naturally fluctuating flows from cycles of drought and flood that produce isolated perennial and intermittent pools that serve as important refugia for fish during dry periods. While there are likely no indicator species of fish that are restricted to intermittently or ephemerally flowing streams in the GP, there are species that can better withstand environmental extremes and may be more likely to be found in isolated pool habitats. Table 10 summarizes studies found during this literature review that were conducted in the GP that compared or characterized fish community composition in perennial and intermittent/ephemeral streams.

Table 10. Great Plains studies of fish in different streamflow duration classes.

Source	Region	Notes	Perennial	Intermittent/ Ephemeral
Anderson et al. (1983)	North-central Texas (Brazos River)	Characterized fish at intermittent site above Possum Kingdom Dam and perennial sites below	Species found only below dam: orangethroat and dusky darters, central stoneroller, bluntnose minnow, blacktail shiner, brook silverside, and blackstripe topminnow	Species found only at upstream, intermittent site: emerald shiner, sand shiner, plains minnow, speckled chub, and Red River pupfish

Source	Region	Notes	Perennial	Intermittent/ Ephemeral
Bramblett and Fausch (1991)	Southeastern Colorado – Purgatoire River and 10 tributaries	Habitat and biota descriptions; tributaries not given a definitive flow classification	Species more associated with perennial river sites: red shiner, sand shiner, flathead chub, longnose dace, channel catfish	Generalist fishes that favor both intermittent and perennial sites: fathead minnow and green sunfish
Falke et al. (2012)	Northeastern Colorado (Arikaree River)	3 segments of River: perennial (fed by aquifer), intermittent, and ephemeral (largely due to pumping)	Not Applicable (N/A)	Authors found that fathead minnow was the best colonizer of formerly dry sites.
Fausch and Bramblett (1991)	Southeastern Colorado – Purgatoire River and 10 tributaries	Characterized fish community composition of perennial river sites and intermittent tributary sites	N/A	Taxa associated more with drier, intermittent sites: fathead minnow, central stoneroller, white sucker, black bullhead, and green sunfish
Smith and Powell (1971)	Southern Oklahoma	Sampled perennial, intermittent, and ephemeral sections of Brier Creek, upstream and downstream of Lake Texoma	Species most associated with perennial sites: Mississippi silverside, common logperch, blacktail shiner, white crappie, shad, orangethroat darter	Taxa most associated with ephemeral sites: fathead minnow, golden shiner, and green sunfish
Ostrand and Wilde (2004)	North-central Texas (upper Brazos River drainage)	Characterized fish assemblage in isolated pools in an intermittent system	N/A	Cyprinodontids and mosquito fish tended to maintain populations or increase in abundance as pools dried, while sharpnose shiner, plains minnow, smalleye shiner, plains killfish, Red River pupfish, and red shiner all decreased in population

The list of amphibian and reptile species used in Nadeau (2015) should be updated to include taxa found in the GP through consultation with regional experts. Habitat preferences of taxa specific to the GP will need to be developed if they are to be used as an indicator of flow duration classes. For instance, in its Habitat Management Guidelines for the Midwest, Partners in Amphibian and Reptile Conservation (Kingsbury and Gibson 2012) identify those species that are most characteristic of certain stream habitats, for all or part of their life cycle (Table 11). From a GP perspective, the ‘midwest’ in this context includes the Dakotas, Iowa, Illinois, Kansas, Michigan, Minnesota, Missouri, Nebraska, and Wisconsin.

Table 11. Characteristic reptiles and amphibian species of different types of stream habitats in the Midwest (Kingsbury and Gibson 2012).

Aquatic Habitat	Characteristic Species*	Notes
Small streams, springs, and seeps	**Salamanders**: four-toed, long-tailed, eastern red-backed **Frogs**: green, pickerel **Snakes**: queen, northern watersnake	Small streams likely include those that are intermittent; while springs and seeps are generally fed by groundwater, they are often isolated from other bodies of water by terrestrial habitats
Rivers and large streams	**Salamander**: mudpuppy+ **Turtles**: alligator snapping, smooth softshell, spiny softshell, northern map, wood **Snakes**: eastern ribbonsnake, northern watersnake, diamond-backed watersnake, queen, red-bellied mudsnake	Generally perennial systems. The mudpuppy is a truly aquatic species that requires water throughout its life cycle, while many of the turtles leave the water only to lay eggs. Two of the snake species overlap from smaller streams, though all the snakes here would be considered semi-aquatic.

*Only includes those species that have ranges overlapping the GP
+Gilled throughout life cycle, aquatic only

In its headwater stream assessment method, Ohio EPA (2012) stipulates salamander species that are indicators of perennial flow (generally those with larval stages longer than 12 months), as well as those that can tolerate intermittent flow. Many of the species listed do not have ranges that include the GP. One perennial indicator species, the longtailed salamander (*Eurycea longicauda*), can be found in parts of IL and MO that are included in the GP, though it is noted that some populations of this species have larval periods that are shorter than 12 months, and Kingsbury and Gibson (2012) denotes this species as characteristic of smaller streams that have a higher likelihood of being intermittent. Species given as tolerating intermittent flow and that are also found in the GP include members of *Ambystoma* such as *A. tigrinum* (eastern tiger salamander) and *A. texanum* (smallmouth salamander), as well as *Hemidactylium scutatum* (four-toed salamander).

Painted turtles (*Chrysemys picta*) occur from the humid east coast through the northern Great Plains and into the PNW. They are generally associated with permanent lentic habitats. In parts of Iowa, they co-occur with the yellow mud turtle (*Kinosternon flavescens*), whose range in Iowa is isolated from its usual range in the southern GP. Christiansen and Bickham (1989) documented that when a lake these turtles were using completely dried, painted turtles moved to remaining water sources (including a stream type habitats), but mud turtles would not. The authors concluded that mud turtles began terrestrial estivation early, a behavior which is likely a hallmark of the drier environment in which they evolved. Therefore, turtles with these types of behavioral strategies may be poor flow duration indicators.

6.2 PROPOSED INDICATORS

Based on the above discussion, as well as study goals, we will largely evaluate indicators used in the Pacific Northwest (Nadeau 2015) and New Mexico (NMED 2011) methods for the Great

Plains. However, additional indicators with positive evidence for determining flow duration in the primary literature, as well as any other priority indicators from Table 4 will also be included:

Geomorphological indicators

- Slope (Nadeau 2015)
- Sinuousity (NMED 2011)
- Floodplain and channel dimensions (aka, entrenchment ratio; NMED 2011)
- In-channel structure/riffle-pool sequence (NMED 2011)
- Substrate sorting (NMED 2011)

Hydrologic indicators

- Water in channel (NMED 2011); includes observations of hyporheic flow and isolated pools
- Hydric soils (NMED 2011); includes sampling of soil moisture and texture
- Sediment on plants and debris (NMED 2011)
- Seeps and springs (NMED 2011)
- Number of woody jams within 10 m of the reach (Mersel and Lichvar 2014)

Biological indicators

<u>Aquatic macroinvertebrates</u>

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

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

<u>Algae</u>

- Presence of filamentous algae (NMED 2011)
- Presence of live or dead algal mats (Topping et al. 2009)

Bryophytes

- Presence of streamer mosses (Topping et al. 2009)
- Presence of liverworts (Fritz et al. 2009, Vieira et al. 2016)
- Presence of pleurocarp and acrocarp bryophytes in the channel and banks (Fritz et al. 2009, Vieira et al. 2016)

Wetland and riparian plants

- Presence of FACW, OBL, and SAV plants, following Nadeau (2015). The regional wetland plant lists encompassing the Great Plains (Lichvar et al. 2016) will be used.
- Absence of rooted vegetation in thalweg (NMED 2011)
- Vegetation differences between riparian zone and adjacent uplands (NMED 2011)

Vertebrates

- Presence of fish, reptiles and amphibians (Nadeau 2015)
- Presence of fish (NMED 2011)

6.0 BIBLIOGRAPHY

6.1 Flow duration assessment methods

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

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