# Review of flow duration methods and indicators of flow duration in the scientific literature: Western Mountains


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Southern California Coastal Water Research Project
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## Statement of the Purpose

This review documents methods and indicators to determine the flow status of streams in the Western Mountains (WM), with an emphasis on field-based methods that distinguish ephemeral from perennial and intermittent streams. WM, within the context of this review, is considered to be wetter, higher-elevation portions of the western US that typically receive over 15” rainfall per year (in contrast to the drier Arid Southwest [ASW]; US Army Corps of Engineers 2008; Omernik and Griffith 2014). States within this region include California, Utah, Colorado, Wyoming, Arizona, Montana, New Mexico, and small portions of South Dakota and Nevada. Within many of these states, non-arid regions occur, such as the North Coast of California, or interior mountains (Figure 1).

Although direct measures of flow duration (e.g., long-term records from stream gauges) are usually preferred, indirect measures of flow duration indicators have two major strengths that make them effective tools for watershed 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 observations of aquatic state. They may even be better than direct observations with short periods of records, which may be influenced by short-term changes that do not reflect typical reach conditions.

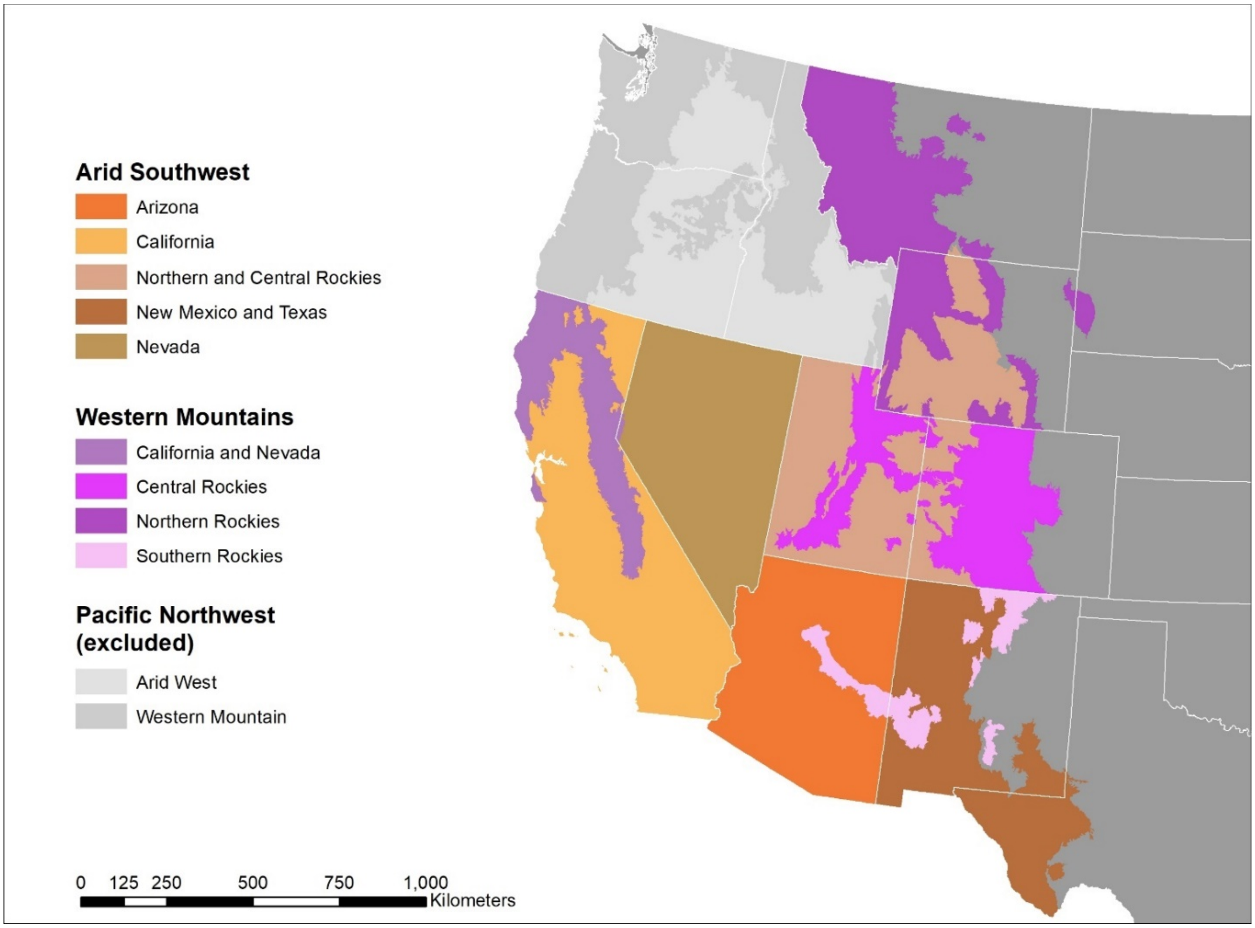


**Figure 1. Ecoregions of the Western Mountains.**

# METHODS

## General approach

To identify potential indicators of flow duration in the WM, we first identified a set of indicators used in established flow duration methods (Figure 2). These indicators were characterized by type (e.g., plants, benthic macroinvertebrates) and endpoint used to assess the indicator (e.g., presence of indicator taxa, abundance). We then supplemented this set with additional indicators whose use was supported by scientific literature and other appropriate sources, but not incorporated into established methods. This full list of potential indicators was then evaluated for 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 2 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 WM? This was assessed based on personal knowledge of ephemeral and intermittent stream systems in the region. 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 or continuous measurement 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, we also noted if there were studies demonstrating efficacy of the indicator in determining flow-duration classes.

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

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

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

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


**Figure 2. Process for identifying indicators of flow duration to assess in the Arid Southwest.**

## Search methods

We built upon previous efforts to conduct a literature review for flow duration indicators in the Arid Southwest (McCune and Mazor 2019) by evaluating sources discovered in that process for relevance to the Western Mountains. We then added to this collection of sources with additional searches of reference libraries (Table 1). Search terms in Table 1 were used as singular search terms, in combination with western mountains associated regions (e.g., Sierra Nevada mountains), and combined into one "OR" search in Web of Science, Google, and Google Scholar. The first titles or abstracts of the 50 search results were reviewed to determine applicability to the western mountains; relevant results (see next section) were then added to a compiled reference library (https://paperpile.com/shared/3iHwBc), although some sources were later excluded following a more thorough review. This compiled library was 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 western mountains.**

| Search Source | Search Date | Key Terms | Hits |
|---|---|---|---|
| Google | 11/9/2018 | "western mountains" | 548,000 |
| Google | 11/9/2018 | "western mountains" AND "flow duration" | 475 |
| Google | 11/9/2018 | "western mountains" AND "flow duration" AND "indicators" | 98 |
| Google Scholar | 11/9/2018 | "western mountains" | 12,000 |
| Google Scholar | 11/9/2018 | "western mountains" AND "flow duration" | 63 |
| Google Scholar | 11/9/2018 | "western mountains" AND "flow duration" AND "indicator" | 43 |
| Google Scholar | 11/9/2018 | mountains stream indicator "sierra nevada" OR "southern cascade" OR arizona OR "new mexico" OR "black hills" OR montana OR wyoming OR klamath "hydrologic regime" | 2,830 |
| Google Scholar | 11/9/2018 | mountains stream indicator "sierra nevada" OR "southern cascade" OR arizona OR "new mexico" OR "black hills" OR montana OR wyoming OR klamath "flow duration" | 1,560 |
| Google Scholar | 11/9/2018 | "western mountains" AND "hydrologic regime" | 115 |
| Google Scholar | 11/9/2018 | "western mountains AND "intermittent stream" | 77 |
| Google Scholar | 11/9/2018 | "western mountains" AND "perennial stream" | 80 |
| Google Scholar | 11/9/2018 | "western mountains" AND "ephemeral stream" | 44 |
| Web of Science | 11/9/2018 | "western mountains" AND ("streamflow duration" OR "flow assessment" OR "intermittent" OR "ephemeral" OR "biological Indicators" OR "clean water act jurisdiction" OR "hydrologic regime" OR "merovoltine" OR "semivoltine" OR "univoltine") | 410,510 |

## Analysis of sources

### Including sites in the review

Sources with available articles were reviewed and annotated to assess the applicability, soundness, clarity, and uncertainty. Annotations were focused on synthesizing the scientific merit of each goal, procedure, result and conclusion reported by the authors, after relevance to the ASW or flow duration classes was evaluated. Sources were reviewed for five elements to warrant inclusion in the library, following the decision tree in Figure 3.

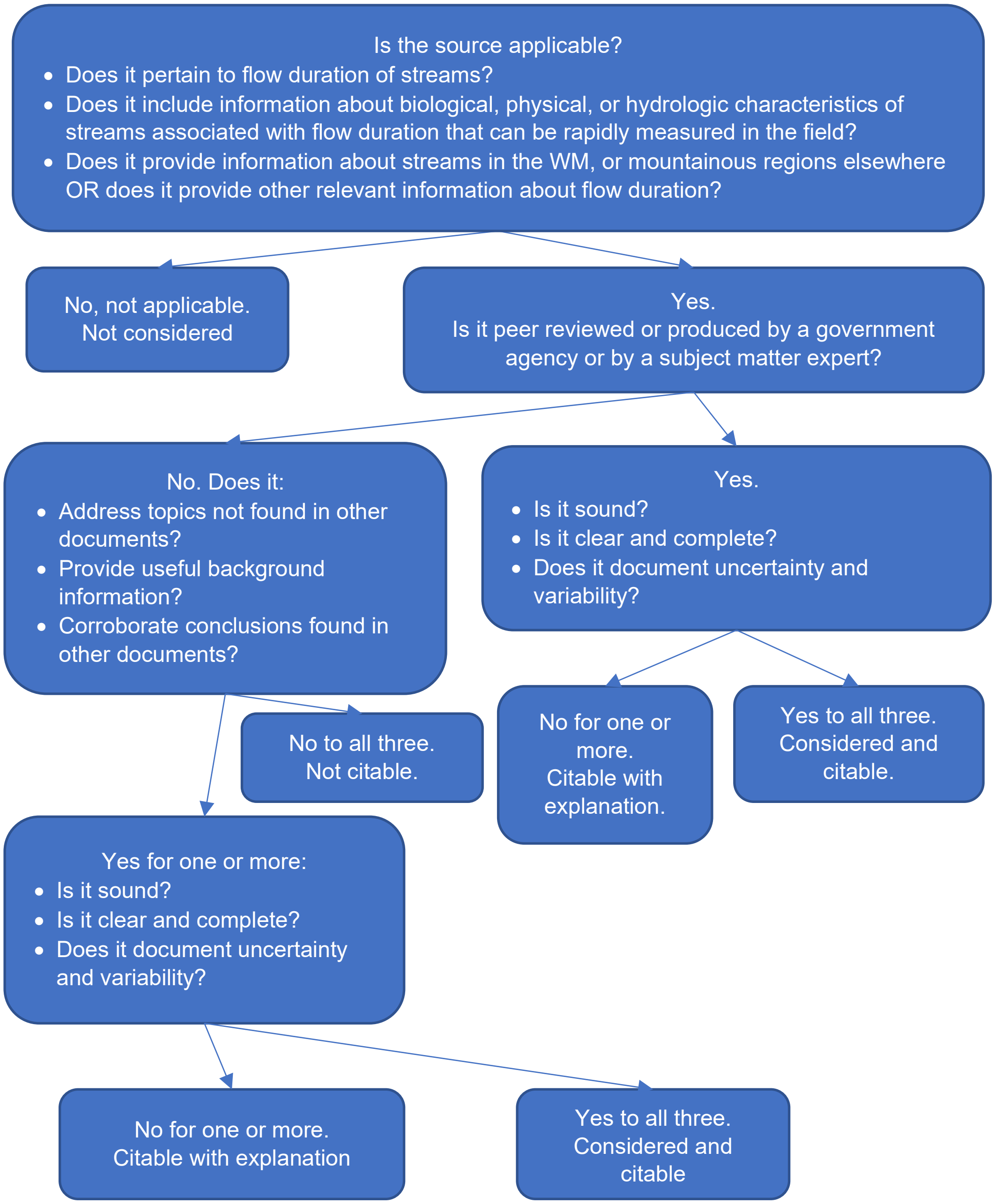


**Figure 3. Decision tree for reviewing sources.**

*Applicability/Utility:* Sources that provide information about the biological, physical, or hydrologic characteristics of streams along a flow duration gradient in the WM were considered applicable. Sources in regions outside the WM may also be considered applicable if other elements of the reference were relevant to the study. Several sources found during searches did not meet this criterion. Factors that limited the applicability of a citation include reliance on intensive hydrologic data (e.g., continuous flow gauge data), or reliance on other data types that could not be rapidly measured in the field (e.g., remote sensing data).

*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. We looked for 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.

### Evaluating information about indicators

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

# RESULTS

## Literature review

All literature (including PDF copies, where available) are included in this endnote library:

https://ftp.sccwrp.org/pub/download/TMP/RaphaelMazor/USEPA_WM_Bibliography.zip

## Flow duration assessment methods

Seven methods were appropriate for evaluating flow-duration classes in the WM (Table 2). An additional three methods were found (Kennard et al. 2010; Trubilowicz et al. 2013; and Berhanu et al. 2015), but were excluded because they lacked a rapid field component, focusing instead on long-term records of measured or modeled flow. Table 3 provides a summary of which indicators were used with which method.

Table 4 provides a summary of the evaluation criteria for each indicator. Indicators that met all criteria were designated as priority indicators. With some exceptions, all priority indicators were proposed for inclusion in the pilot study in the WM; rationale for excluding priority indicators, or for including non-priority indicators, is provided in the table.

**Table 2. Methods for assessing flow duration and their associated indicators. Asterisks indicate that the protocol includes portions of the WM.**

| | | | Indicators | | |
|---|---|---|---|---|---|
| **Source** | **Geographic location** | **Represented classes** | **Biological** | **Geomorphological** | **Other** |
| Nadeau (2015a) | Pacific Northwest, USA* | Ephemeral, perennial and intermittent | Benthic macroinvertebrate, wetland plants, riparian corridor, fish, amphibians/snakes | Slope, evidence of erosion/deposition, floodplain connectivity | |
| Topping et al. (2009) | Oregon, USA* | 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 | |
| Fritz et al. (2006) | Temperate USA (Indiana, Kentucky, Ohio, Illinois, New Hampshire, New York, Vermont, West Virginia, and Washington)* | 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 |
| NC Division of Water Quality (2010) | North Carolina | Intermittent and perennial | Iron oxidizing bacteria, leaf litter, organic debris drift accumulation, fibrous roots, 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, sediment on plants/debris, soil chroma |
| Surface Water Quality Bureau, NM Environment Department (2011) | New Mexico, USA* | 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, seeps/springs | Water in channel, hydric soils, sediment on plants or debris, hyporheic zone/groundwater table |
| Gallart et al. (2017) | Mediterranean Europe | Intermittent-pools, intermittent-dry, | | | Hydrologic metrics (based |

| | | | | | |
|---|---|---|---|---|---|
| | | episodic-ephemeral, perennial; Hyperrheic, eurheic, oligorheic, arheic, hyporheic/dry | | | on modeled or recorded flow), citizen observations |
| Svec et al. (2005) | Eastern Kentucky | Ephemeral, intermittent, perennial | | Bankfull width & depth, entrenchment ratio, slope, watershed area, estimated flood plain area | |
| Ohio EPA (2012) | Ohio | Ephemeral, intermittent/perennial (warm water), perennial (cold water) | Fish, benthic macroinvertebrates, amphibians, exposed plant roots on banks, riparian/in channel vegetation, organic matter | Bankfull width & depth, bed & bank presence, erosional/depositional channel features, sinuosity, estimated channel gradient, substrate sorting, groundwater presence, leaf litter, seeps & springs | Water quality measurements, flowing water in channel |
| Straka et al. (2019) | Czech Republic | Intermittent, near-perennial, and perennial | Benthic macroinvertebrates | | |
| McCleary et al. (2012) | Alberta, Canada | Upland, ephemeral or water source areas, intermittent, intermittent/transitional/small permanent, small permanent or large permanent | In channel vegetation presence | Bankfull width, undercut width, substrate sorting, erosional/depositional channel features, bed and bank presence, moisture regime | Water in channel |
| Savage and Rabe (1979) | Idaho | Ephemeral, “spring streams” and perennial | | Gradient, substrate | |

**Table 3. Summary of indicators included in flow-duration assessment methods.**

| Indicator | Temperate USA | Oregon | North Carolina | New Mexico (Phase 1) | New Mexico (Phase 2) | Pacific Northwest | Mediterranean | Kentucky | Ohio | Czech Republic |
|---|---|---|---|---|---|---|---|---|---|---|
| *Geomorphology* | | | | | | | | | | |
| Bankfull width and depth | X | | | | | | | X | X | |
| Continuous bed and banks presence | | X | X | | | | | | | |
| Depositional or erosional features in the channel | | X | X | | | | | | X | |
| Depositional or erosional features on the floodplain | | | X | | | | | | | |
| Distinct substrate composition in streambed from adjacent uplands | X | X | X | X | | | | | | |
| Entrenchment ratio | X | | | X | | | | X | | |
| Evidence of active floodplain | | | | | | | | | | |
| Evidence of relict floodplain | | | X | | | | | | | |
| Natural valley presence | | | X | | | | | | | |
| Presence of headcuts | X | X | X | | | | | | | |
| In-channel sequences of erosional and depositional features | X | X | X | X | | | | | | |
| Stream order | | | X | | | | | | | |
| Sinuosity | X | X | X | X | | | | | X | |
| Slope | X | | | | | X | | X | X | |
| *Hydrology* | | | | | | | | | | |
| Continuous logged data | X | | | | X | | | | | |
| Groundwater observation | X | X | X | X | | | | | X | |
| Distribution of leaf litter or debris | X | | X | | | | | | X | |
| Hydric soils or redoximorphic features | | X | | X | | | | | | |
| Modeled hydrology | | | | | | | X | | | |
| Observed aquatic state | X | | | X | | | X | | X | |
| Reported aquatic state from interviews | | | | | | | X | | | |
| Observed or reported soil saturation | X | X | | X | | | X | | | |
| Observation of baseflow | | | X | | X | | X | | | |
| Presence of wrack or drift lines | | X | X | | | | | | | |
| 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 | |
| Velocity | X | | | | | | | | | |
| *Biology* | | | | | | | | | | |
| Iron-oxidizing bacteria or fungi | | X | X | X | | | | | | |
| Algae | X | X | X | X | X | | | | | |
| Lichens | | X | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bryophytes | X | X | | | | | | |
| Wetland vegetation | | X | X | | | X | X | |
| Upland vegetation in channel | | X | X | X | | | X | |
| Riparian vegetation | | X | | X | | X | X | |
| Aquatic macroinvertebrates - Presence | X | X | | X | | X | X | |
| Aquatic macroinvertebrates - Abundance | X | | X | | X | X | X | X |
| Aquatic macroinvertebrates - Indicator taxa | | X | X | | X | X | X | X |
| Aquatic macroinvertebrates – Traits | | | | | | | | X |
| Amphibians – Presence | X | X | | | X | X | X | |
| Amphibians - Abundance and diversity | X | | X | | | | X | |
| Reptiles – Presence | | X | | | | X | | |
| Fish – Abundance | | | X | | X | | X | |
| Fish – Presence | | X | | X | | X | | |

**Table 4. Evaluation criteria for indicators identified in the literature review. 1: Non-priority indicator proposed for inclusion because it is required by the New Mexico protocol (NMED 2011).**

| 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** |
| 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 | X | X | | X | | No | X | X | **Yes** |
| Entrenchment ratio | X | X | | X | X | No | | X | **Yes** |
| Evidence of active floodplain | | X | | X | | No | X | X | **No** |
| Evidence of relict floodplain | | X | | X | | No | X | X | **No** |
| Natural valley presence | | X | | X | | No | | X | **No** |
| Presence of headcuts | X | X | | X | X | No | X | X | **Yes[1]** |
| 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 | X | X | X | X | X | Yes | X | X | **Yes** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Hydrology* | | | | | | | | | |
| Continuous logged data | X | X | X | | X | No | X | | **No** |
| Groundwater observation | X | X | X | | X | No | X | | **No** |
| Distribution 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** |
| Velocity | | X | | X | X | No | X | X | **No** |
| *Biology* | | | | | | | | | |
| Iron-oxidizing bacteria or fungi | X | X | X | X | X | Yes | X | X | **Yes** |
| 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** |
| 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** |
| Amphibians - Presence | X | X | X | X | X | Yes | | X | **Yes** |
| Amphibians - Abundance and diversity | X | X | X | | X | No | | | **No** |
| 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** |
| **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** |
| Woody jams | | X | X | X | X | No | X | X | **No** |

## Pacific Northwest

For purposes of classifying perennial, intermittent, and ephemeral streams in the Pacific Northwest (including the portion of that region within the WM), 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) from the US Army Corps of Engineers (2013); and 5) valley slope. Additional indicators, such as the presence of fish, aquatic stages of amphibians, and evidence of sediment erosion or deposition, are also considered. These five indicators will serve as the foundation for evaluation of flow duration assessment methods in the WM. Indicators are measured in an objective fashion, without requiring subjective or qualitative visual assessments by practitioners.

Indicators are evaluated with a simple branching flow-chart (Figure 4), 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.

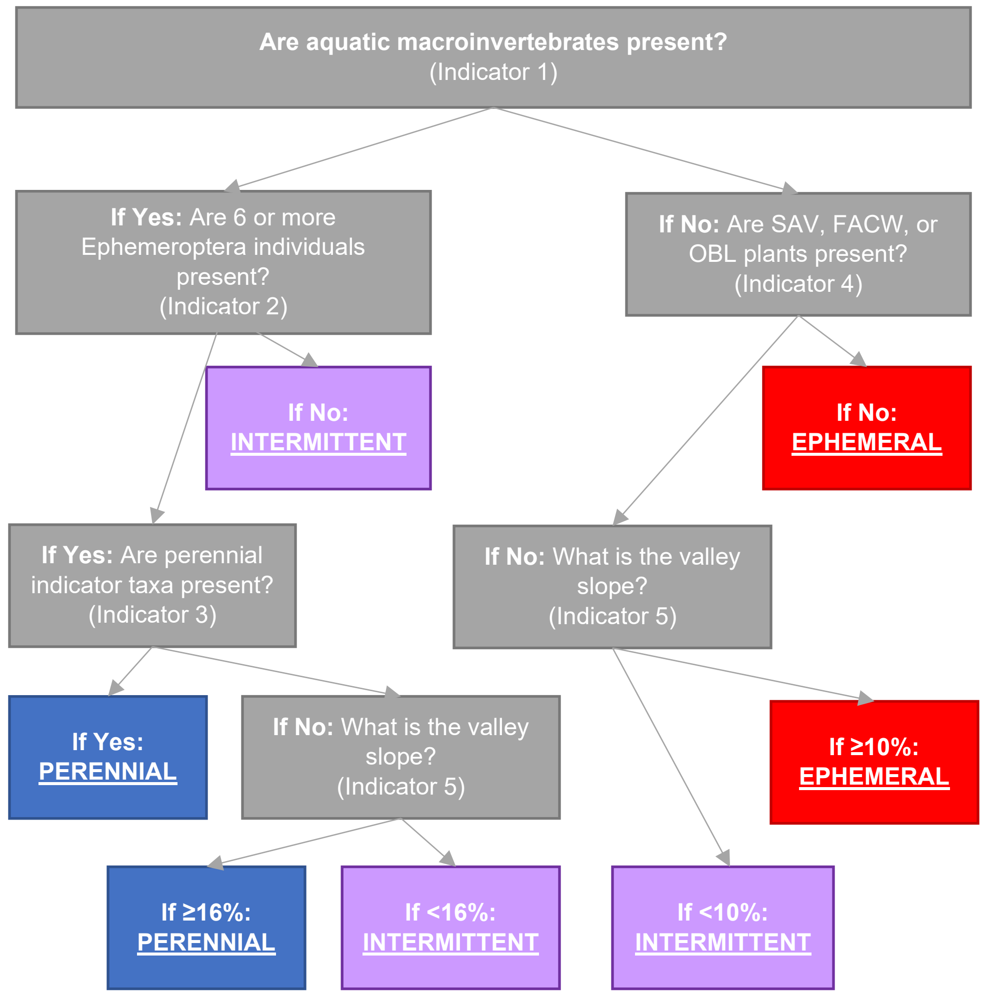


**Figure 4. Flowchart used to determine flow class in the Pacific Northwest method (adapted from Nadeau 2015).**

## Oregon Interim 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 at the reach. This method was developed for a region that includes the WM. 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 it's above 25, it is considered perennial. Single indicators (e.g., presence of fish, amphibians, or aquatic macroinvertebrates) may trump an "ephemeral" score. In contrast to Nadeau (2015), assessing the strength of the indicators requires subjective visual assessments by practitioners.

## New Mexico

The New Mexico Environment Department developed a two-phase method for assessing flow duration (NM Environment Department 2011) in both arid and mountainous regions of that state.

The first phase is more rapid, and it is sometimes sufficient to classify a stream as perennial, intermittent, or ephemeral. This first phase relies on qualitative sampling of benthic macroinvertebrates, fish, filamentous algae, and other organisms, plus field observation of channel morphology and soils. In some cases, a second phase consisting of quantitative fish and benthic macroinvertebrate samples may be necessary. This second phase also requires the use of continuous loggers or stream gauges to measure water presence. In this method, 14 indicators of flow duration ("attributes") are scored, yielding a quantitative index that forms the basis of the classification (Table 5). Notably, this method may result in ambiguous situations (gray rows in Table 5), which may be resolved by more intensive "level 2" analysis, and by investigation of adjacent reaches. Certain indicators (specifically, fish and aquatic macroinvertebrates) may result in a perennial designation, even if scores are low. Like Nadeau (2015), this method was designed for application in arid regions. Like Topping et al. (2009), many indicators require subjective visual assessment by practitioners.

**Table 5. Score interpretation for the New Mexico method.**

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

## Mediterranean Europe

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

In contrast with other methods, this assessment method classifies streams into four classes, reflecting the predominant aquatic states: intermittent-pool, intermittent-dry, episodic-ephemeral, or perennial.

Methodology for interviews is documented in Gallart et al. (2016). Interviews target people encountered in the vicinity of a stream in question, as well as with regional experts with a "professional or leisure" relationship with the river. 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.

Hydrologic rainfall-runoff models are interpreted by calculating a set of flow metrics that are associated with different aquatic states (Gallart et al. 2012). These metrics relate to flow permanence (Mf), pool permanence (Mp), and dry-period permanence (Md; Figure 5). Similar models have been developed for use in the WM region (e.g., runoff models developed for the Sawtooth Mtns., Arp et al. 2006), but require intensive investments for model development and are thus not considered an appropriate methodology in this review.

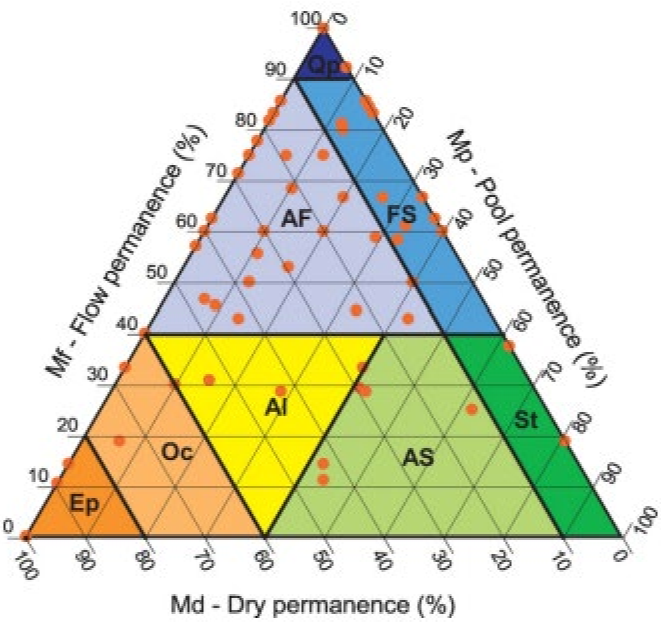


**Figure 5. Plot used for classifying flow duration based on three metrics calculated from hydrologic model outputs.**

## North Carolina

This method, developed by the North Carolina Division of Water Quality (2010), includes 9 biological, 11 geomorphic, and 6 hydrologic indicators to classify a stream as 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 individually scored and then summed to yield an overall index score. Some indicators (or more robustly evident indicators) are weighted higher than others and the presence of specific taxa (fish, crayfish, amphibians, or clams) can result in a perennial designation, even if the overall index score is 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 receives considerably more rainfall than the WM.

### 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. The suite of methods described is more comprehensive than the other listed methods, but no conclusive flow duration classification is drawn upon at the end of the methods. Publications following this report (Fritz et al. 2009; Johnson et al. 2009; Fritz et al. 2009; Roy et al. 2009; Datry et al. 2014) assess the effectiveness of each indicator separately. These methods have been applied widely throughout the USA, mostly for forested headwater streams outside the WM (the exception being Washington state).

### 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 6). 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 6).

**Table 6. 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 |

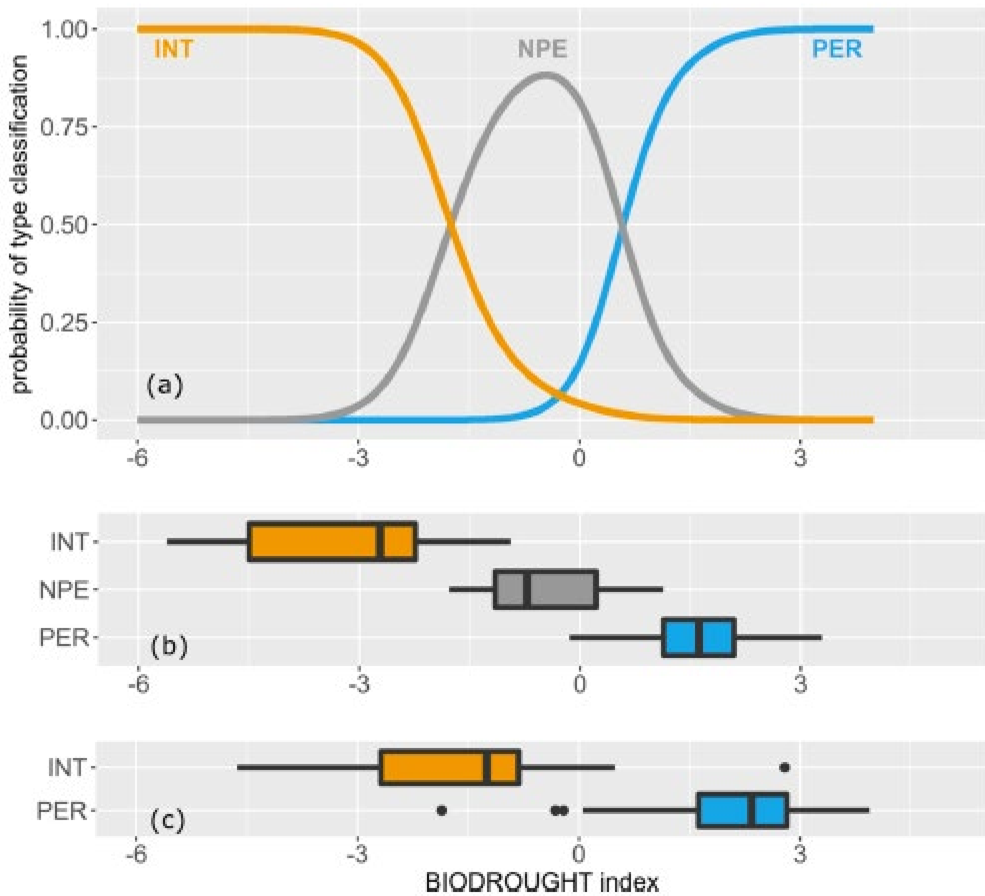


**Figure 6. Relationship between Biodrought index scores and flow classes, from Straka et al. (2019). Top panel shows the probability of classification as the index score increases. The second panel shows scores associated with calibration data. The bottom panel shows scores associated with independent 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 for Straka et al. (2019) 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 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.

## INDICATORS IN THE WESTERN MOUNTAINS

A review of literature describing indicators in the WM shows general support for indicators used in current flow duration assessment methods, particularly biological indicators. A number of potential new indicators not used in any of the methods in Table 2 are also discussed, and summarized in Table 7. We discuss each class of indicators and determine whether specific indicators should be included in the evaluation of flow duration assessment methods in the WM, with particular attention to the indicators included in Nadeau (2015). Relevant information from personal experience or communication with regional experts is included as well.

## Geomorphological Indicators

Geomorphic indicators in the WM are defined primarily by Mersel and Lichvar (2014), while many of the specific relationships between hydrology and channel geometry are initially defined for streams in the Western US by Hedman and Osterkamp (1982). Changes in geomorphological indicators over time can be indicative of a change to ephemerality from a perennial state (e.g., bed and bank destabilization), but one-time observations of indicators may be more related to storm intensity, stream power, and substrate composition (Friedman and Lee 2002). Outside of the temporary stream indicators defined by Mersel and Lichvar (2014), there were no studies found that defined differences in stream geomorphology based on flow duration classification; rather, there were studies that characterized geomorphology for WM streams based on channel types – e.g., cascade, step pool, plane bed and pool riffle steam morphologies typified for the region by Wohl and Merritt (2008).

### Tufa deposits

In alkaline waters rich in carbonate, tufa deposits may form under certain conditions. Tufa deposition processes are highly dependent on physiochemical and biological factors not directly related to flow duration (Ford and Pedley 1996). For example, Ford and Pedley (1996) described areas throughout the US (including sites in the WM) in which tufa formations occur, including fossil tufa sites, where historical conditions allowed for the formation of tufa but are no longer actively forming – tufa presence is not representative of present-day hydrologic conditions. No studies were found to support the use of tufa deposits as an indicator of flow duration, as the presence of such formations is not an indicator of present-day streamflow. 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.

## Hydrologic Indicators

Several studies supported the use of certain hydrologic indicators of flow duration, particularly direct observation of flow, groundwater, and soil conditions (Turner and Richter 2011; Gallart et al. 2016). In dry channels, several methods distinguish intermittent from ephemeral streams by evaluating the distribution of leaf litter or looking for the presence of wrack lines (e.g., Topping et al. 2009; NMED 2011). As with many geomorphological indicators, the distribution of organic material in the stream channel is more of an indication of stream power than flow duration, and thus has limited utility outside of low-power headwater systems. An important exception is the development of hydric soils, which are produced by the anoxic conditions associated with prolonged inundation (Cowardin et al. 1979). A couple studies showed that water chemistry is distinct in intermittent and perennial streams (e.g., Bonada et al. 2006; Bogan 2017). Notably, solute concentrations tend to be higher in intermittent streams, particularly towards the end of the drying period. However, values overlapped considerably among flow duration classes, suggesting that this would not be a consistent indicator for flow duration assessment.

### Woody jams

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

## Biological Indicators

In contrast to the many of the other indicators mentioned above, biological indicators are often directly related to flow duration. Consequently, many studies corroborated relationships between these indicators and flow duration, particularly aquatic macroinvertebrates and plants.

### Aquatic macroinvertebrates

Several methods presume that ephemeral streams are unable to support aquatic macroinvertebrates, with the exception of short-lived taxa like Culicidae. Although there are numerous studies of aquatic invertebrates in the WM, no studies we are aware of examine ephemeral streams in this region; studies that explore the role of streamflow duration typically located perennial sites in the WM, and intermittent or ephemeral sites in adjacent portions of the ASW (e.g., Bogan et al. 2013). De Jong et al. (2015) sampled ephemeral streams in arid (i.e., non-mountainous) portions of New Mexico, collecting 86 different taxa of aquatic macroinvertebrates within a few days of the onset of flow. Many of these taxa had aerially dispersing adult life-stages, and most were found only in ephemeral reaches that were connected to perennial reaches. Newly hatched larvae of the mayfly *Callibaetis* were found within 1 day of the onset of flow, as were adults of taxa that can aerially disperse (typically beetles). Tadpole shrimp (*Triops*) were also frequently observed, as partially terrestrial taxa (e.g., annelids). However, these observations are likely to have only a small impact on the ability to use the presence of aquatic invertebrates as an indicator of intermittent or ephemeral flow. First, assessments should be timed to avoid the first few days of the onset of flow, after which ephemeral streams will no longer support aquatic macroinvertebrates. Second, additional exclusions can be made, such as ignoring early instars (which are unlikely to be detected in rapid field methods), aerially dispersing adults, and partially terrestrial fauna.

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. While many studies demonstrate consistent compositional differences between perennial and intermittent streams (e.g., Bramblett and Fausch 1991; Rader and Belish 1999), only some presented data in a way to ascertain the value of specific taxa to indicate flow status. Typically, results are presented at species or genus level, when field indicators may require identifications at family level or lower.

Nadeau (2015) makes use of studies by the Xerces society (i.e., Mazzacano and Black 2008; Blackburn 2012) to identify perennial indicator taxa in the PNW, and it is likely that most of these taxa have similar indicator value in the rest of the WM. However, a few studies show that some taxa exhibit different habitat affinities in the WM. Many studies noted that intermittent reaches adjacent to perennial waters may support perennial indicator taxa, suggesting that this indicator may reflect hydrologic patterns at larger spatial scales than needed of flow-duration assessment methods.

In a study of drought-impacted streams of the Sierra Nevada, California, Herbst et al. (2019) noted that intermittency was a large driver of change in invertebrate communities. Sites that experienced intermittency were associated with midges, as well as the alderfly *Sialis,* whereas streams that experienced continuous flow throughout the drought had higher densities of mayflies, stoneflies, and caddisflies, including several perennial indicators identified by Mazzacano and Black (2008): Rhyacophilidae, Hydropsychidae, and Perlidae. They also noted that filter feeders had lower densities at intermittent streams, compared to continuously-flowing streams.

Straka et al. (2019) identified numerous taxa indicative of either perennial or intermittent flows in their study of Czech streams, and their list of taxa diverges from those of Blackburn (2012) in several aspects, at least partly due to the different taxonomic resolution of the two studies.

**Mollusks**

In general, support was strong 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). 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*. Although they are less widespread than many gastropods, freshwater mussels are also likely to be good indicators of perennial flow, some species have been observed in perennial pools within intermittent streams (e.g., Clark 2010). Fingernail clams (Sphaeriidae) are not treated as a perennial indicator taxon, but some support for this classification is found in Lusardi et al. (2016). However, Straka et al (2019) identified *Pisidium* as an indicator of intermittent flow.

**Mayflies**

No mayfly families are considered to be an indicator of perennial flow in Blackburn (2012), although some studies suggest that some taxa show a preference for perennial flow (e.g., Isonychidae, King et al. 2015). Some studies support Baetidae as a perennial indicator (e.g., Bonada et al. 2006; Bramblett and Fausch 1991), while others suggest they prefer intermittent flow (e.g., Miller and Brasher 2011). 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 supported 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). Few studies indicated if Pteronarcyidae were collected, suggesting that this taxon may be too rare to be a useful indicator in the WM.

Although Capniidae are listed as an indicator of intermittent flow in Blackburn (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 flows (in Taeniopterygidae, Capniidae, Perlodidae, and Nemouridae), and numerous indicators of perennial flow (species in Nemouridae, Perlidae, Perlodidae, Chloroperlidae, and Leuctridae). One *Isoperla* species (i.e., *I. tripartita*) was an indicator of intermittent flows, whereas two species (i.e., *I. oxlepis* and *I. rivularum*) were indicators of perennial flows, suggesting that even genus-level identifications may be too coarse to provide meaningful indication of flow duration.

**Caddisflies**

Several studies support the use of Hydropsychidae, and to a lesser extent, the other three families (i.e., Philopotamidae, Rhyacophilidae, and Glossosomatidae) as indicators of perennial flow (Bonada et al. 2006; Miller and Brasher 2011; Erman and Erman 1995). Several studies suggested that additional families, such as Brachycentridae or Calamoceratidae, may also be a good indicator of perennial flow in parts of the WM (Bonada et al. 2006; Miller and Brasher 2011). Staka et al. (2019) identified a handful of indicator species for intermittent flows in Czech streams (Beraeidae, Phryganeidae, and numerous species in Limnephilidae), and numerous indicators of perennial flows in several families (including Glossosomatidae, Hydropsychidae, Limnephilidae, Phryganeidae, Polycentropidae, and Rhyacophilidae).

**Beetles**

Several studies showed that elmid beetles showed a strong preference for perennial streams, but that they are occasionally found in intermittent reaches as well, particularly if they 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 ASW. Psephenidae were 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 (e.g., Hydrophilidae: Bonada et al. 2006; Bogan and Lytle 2007), and some are documented ephemeral streams (De Jong et al. 2015). Straka et al. (2019) identified several indicators of intermittent flow in Czech streams (mostly Dytiscidae, Hydrophilidae, Helophoridae, and Hydraenidae), as well perennial streams (several Elimdae, as well as Dytiscidae, Gryinidae, Hydraenidae, and Scirtidae).

### Odonata

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 taxa to be indicative of perennial flows, Cordulegastrid taxa were excluded from intermittent streams (in agreement with Blackburn 2012), whereas Calopterygidae were more widespread (in disagreement with Blackburn 2012).

### Megaloptera

Corydalidae are listed as an indicator of perennial streams in Blackburn (2012), but some reports from montane regions in the arid southwest (e.g., Bogan and Lytle 2007) considered them to be indicative of intermittent conditions. Cover et al. (2015) describes two genus-groups within this family: The *Neohermes*-*Protochauliodes* group, which is well adapted to intermittency by building hyporheic aestivation chambers to survive the dry period (Figure 7), 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 7. Neohermes aestivation chamber in a dry streambed in Arizona (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. Challenges with identifying this group in the field may make them impractical for use in a field-based flow duration assessment method.

**Other aquatic invertebrates**

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*.

## Algae

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

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

Dormant algal propagules may accumulate in the dry streambed and be resuscitated in lab conditions. This approach has been proposed as a way to assess ecological conditions of dry lakes and streambeds (Carvalho et al. 2002; Robson et al. 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.

## 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. (2012a, 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.

### 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 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 of which have very long life-spans (i.e., decades). Therefore, they are well suited to reflect local, long-term conditions in a way that fish or invertebrates cannot.

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 occurrence after diversion of perennial flow along stream reaches in the Routt National Forest, CO. Reynolds and Shafroth (2017) noted a number of plant species indicative of perennial versus intermittent flow regimes in high and low elevation streams in the Colorado Basin. Although that study did not identify ephemeral streams, the authors report that the driest streams in their study were dominated by upland plants, such as sagebrush and juniper (Lindsay Reynolds, personal communication). Thus, the taxonomic composition of riparian and wetland plants may be an effective indicator of flow duration.

### Vertebrates

Several flow duration assessment methods use the presence of vertebrates as indicators of perennial or intermittent flow. The list of species used in Nadeau (2015) should be updated to include taxa found in the WM through consultation with regional experts. Habitat preferences of taxa specific to the WM will need to be developed if they are to be used as an indicator of flow duration classes.

## PROPOSED INDICATORS

For the present study, we will evaluate indicators for the Pacific Northwest (Nadeau 2015) and New Mexico (NMED 2011):

### Geomorphological indicators

- Slope (Nadeau 2015)
- Sinuosity (NMED 2011)
- Floodplain and channel dimensions (aka, entrenchment ratio; NMED 2011)
- In-channel structure (NMED 2011)
- Substrate sorting (NMED 2011)

### Hydrologic indicators

- Water in channel (NMED 2011)
- Hydric soils (NMED 2011)
- Sediment on plants and debris (NMED 2011)
- Seeps and springs (NMED 2011)

- Number of woody jams within 10 m of the reach

## Biological indicators

### Aquatic macroinvertebrates

- 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). Additional taxa recommended by the Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT) will also be noted. Other taxa detected in the field will be reported at the family level, if possible. If lab-analyzed data are available from samples collected at the same site, these will be used as well.
- Available data should be evaluated to ascertain if indicator taxa can be identified in lab-analyzed samples.

### Terrestrial arthropods

- No indicators proposed for evaluation in the current study.
- Available data should be evaluated to ascertain if indicator taxa can be identified in lab-analyzed samples.

### Algae

- Presence of filamentous algae (NMED 2011)
- Presence of live or dead algal mats
- Available data should be evaluated to ascertain if indicator taxa can be identified in lab-analyzed samples.

### Bryophytes

- Presence of streamer mosses (Topping 2009)
- Presence of liverworts
- Presence of pleurocarp and acrocarp bryophytes in the channel and banks.
- Available data should be evaluated to ascertain if indicator taxa can be identified in lab-analyzed samples.

### Wetland and riparian plants

- Presence of FACW, OBL, and SAV plants, following Nadeau (2015). The regional plant list for the Arid West shall be used (Lichvar et al. 2016).
- Absence of rooted vegetation in thalweg (NMED 2011)
- Differences of vegetation between riparian zone and adjacent uplands (NMED 2011)

### Vertebrates

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

- Presence of fish (NMED 2011)

**Table 7. Select examples of ASW indicators and levels associated with flow-duration classes.**

| Source | Region | Notes | Indicator Class | Perennial | Intermittent | Ephemeral |
|---|---|---|---|---|---|---|
| **Caskey et al. (2015)** | Colorado Rocky Mtns. – Routt NF | Flow diversion experiment, summarizing vegetation changes above and below diversions | Vegetation taxa | Associated (labeled as obligate wetland species): *Carex utriculata, Mertensia ciliate, Salix planifolia, Salix wolfii, Veronica americana* | | |
| **Rader and Belish (1999)** | Colorado Rocky Mtns. – St. Louis Creek | Flow diversion experiment, summarizing vegetation changes above and below diversions | Macroinvertebr -ate density | Associated taxa: Ephemeroptera, *Baetis bicaudatus, Drunella coloradensis, Cinygmula* spp. | | |
| **Bramblett and Fausch (1991)** | Southeastern Colorado – Purgatoire River | Habitat and biota descriptions | Macroinvertebr -ate taxa | Associated taxa: *Choroterpes mexicanus, Microcylloepus* sp., *Cheumatopsyche, Hydropsyche,* Simuliidae | | Distinctly missing functional feeding groups present in perennial rivers (scrapers and predators)<br><br>Dominated by collector-gatherers |
| **Reynolds and Shafroth (2017)** | Upper Colorado River Basin | Riparian plant traits for high and low elevation streams | Vegetation taxa – at both high and low elevation | Associated taxa: *Equisetum arvense, Rosa woodsii* | Associated taxa: *Sporobolus cryptandrus, Gutierrezia sarothrae* | |
| **Straka et al. (2019)** | Central Europe **Not in WM* | Species density and frequency of occurrence assessed for perennial, near-perennial and intermittent streams | Macroinvertebr -ate taxa | Strongly Associated Taxa: *Dugesia gonocephala, Baetis muticus, Baetis rhodani s.1., Leuctra sp., Hydropsyche sp.* | Strongly Associated Taxa: *Eiseniella tetraedra, Brachyptera risi, Parametriocne-mus stylatus, Paraphaenoclad -ius sp., Marionina sp.* | |

# Bibliography

## Flow duration assessment methods

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

### Review

McCune, R.D. and Mazor, K. 2019. *Review of flow duration methods and indicators of flow duration in the scientific literature: Arid Southwest*. Technical Report #1063. Southern California Coastal Water Research Project. Costa Mesa, CA. https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1063_FlowMethodsReview.pdf

### Methods

**Mediterranean Europe**

Gallart, F., Cid, N., Latron, J., Llorens, P., Bonada, N., Jeuffroy, J., … Prat, N. (2017). TREHS: An open-access software tool for investigating and evaluating temporary river regimes as a first step for their ecological status assessment. *The Science of the Total Environment*, *607-608*, 519–540. https://doi.org/10.1016/j.scitotenv.2017.06.209

***Related Sources***

Belmar, O., Velasco, J., & Martinez-Capel, F. (2011). Hydrological classification of natural flow regimes to support environmental flow assessments in intensively regulated Mediterranean rivers, Segura River Basin (Spain). *Environmental Management*, *47*(5), 992–1004. https://doi.org/10.1007/s00267-011-9661-0

Gallart, F., Llorens, P., Latron, J., Cid, N., Rieradevall, M., & Prat, N. (2016). Validating alternative methodologies to estimate the regime of temporary rivers when flow data are unavailable. *The Science of the Total Environment*, *565*, 1001–1010. https://doi.org/10.1016/j.scitotenv.2016.05.116

Gallart, F., Prat, N., Garca-Roger, E. M., Latron, J., Rieradevall, M., Llorens, P., … Froebrich, J. (2012). A novel approach to analysing the regimes of temporary streams in relation to their controls on the composition and structure of aquatic biota. *Hydrology and Earth System Sciences*, *16*(9), 3165–3182. https://doi.org/10.5194/hess-16-3165-2012

Prat, N., Gallart, F., Von Schiller, D., Polesello, S., García-Roger, E. M., Latron, J., … Froebrich, J. (2014). THE MIRAGE TOOLBOX: AN INTEGRATED ASSESSMENT TOOL FOR TEMPORARY STREAMS. *River Research and Applications*, *30*(10), 1318–1334. https://doi.org/10.1002/rra.2757

**New Mexico**

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