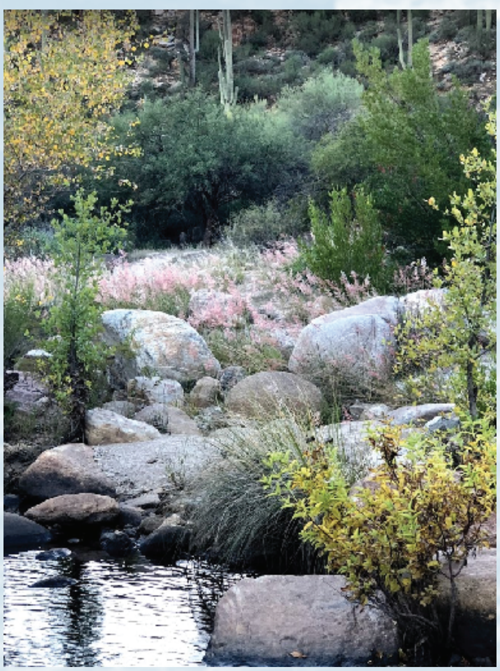
Review of Flow Duration Methods and Indicators of Flow Duration in the Scientific Literature: Arid Southwest



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Southern California Coastal Water Research Project
Technical Report 1063

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STATEMENT OF THE PURPOSE

The purpose of this review is to document methods and indicators that may be used to determine the flow status of streams in the Arid Southwest (ASW), with an emphasis on field-based methods that distinguish ephemeral from perennial and intermittent streams. ASW, within the context of this review, was considered arid to semi-arid regions within US states, defined as regions that typically receive under 15” rainfall per year (US Army Corps of Engineers 2008, Omernik and Griffith 2014). States within this region include California, Nevada, Arizona, New Mexico, Utah, Colorado, and portions of Texas. Within many of these states, non-arid regions occur, such as the North Coast of California, or interior mountains (Figure 1).

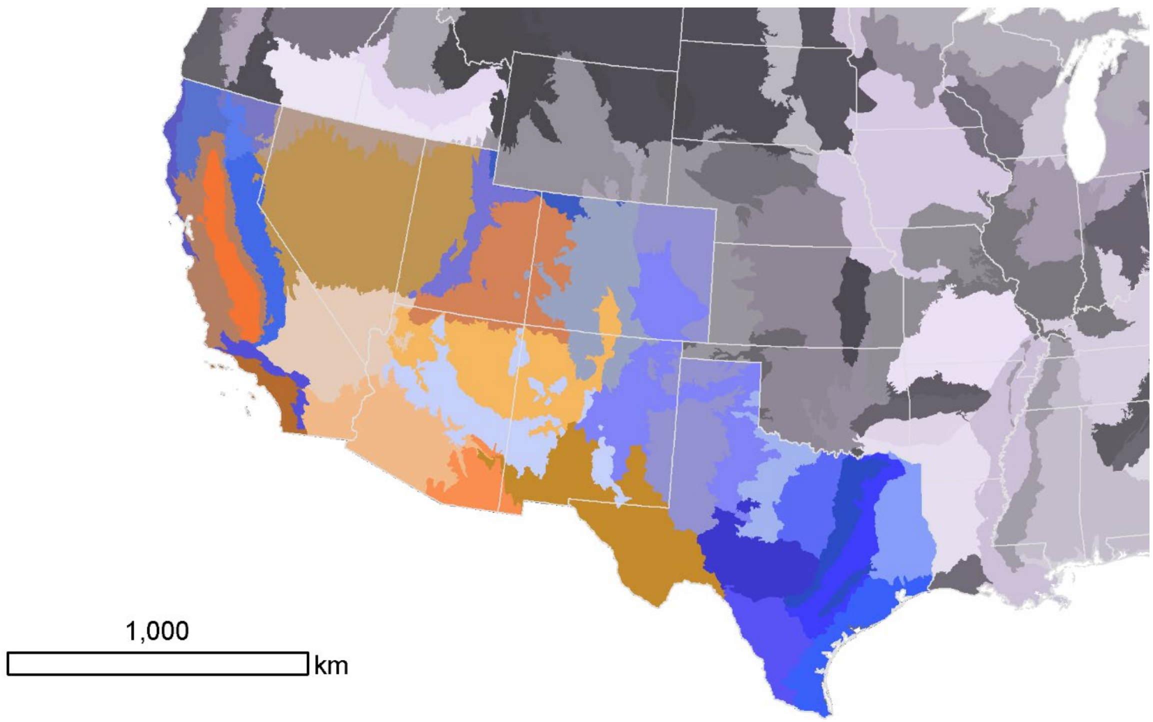

Figure 1. Ecoregions of the Arid Southwest (Omernik and Griffith 2014). Brown tones indicate arid ecoregions, blue tones indicate non-arid ecoregions, and gray tones indicate regions outside the Southwest.

METHODS

General approach

In order to identify potential indicators of flow duration to evaluate in the ASW, 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 were not incorporated into established methods. This full list of potential indicators was then evaluated for a number of key criteria:

Consistency: Does it work? Is there evidence from appropriate sources (see below) that the indicator can discriminate flow classes across different environmental settings, seasons, etc.? Indicators were consistent if it was used in at least 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 ASW? 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 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 analysis in the ASW. At a minimum, this list is expected to include the indicators used in Nadeau (2015), accompanied by appropriate indicators from other sources.

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

Search methods

Search terms in Table 1 were used as singular search terms, in combination with "Arid Southwest", 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 for to determine applicability to the ASW, flow duration indicators or stream classification; relevant results (see next section) were then added to a compiled reference library (https://paperpile.com/shared/xsJuYT), 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 arid southwest

Search Source	Search Date	Key Terms	Hits
Google	12/6/2017	Arid Southwest	26,700,000
Google	12/6/2017	Biological indicators	997,000
Google	12/6/2017	Clean Water Act jurisdiction	11,200,000
Google	12/6/2017	Ephemeral streams	280,000
Google	12/6/2017	Intermittent streams	580,000
Google	12/6/2017	Merovoltine aquatic	1,280
Google	12/6/2017	Perennial streams	919,000
Google	12/6/2017	Semivoltine aquatic	12,100
Google	11/27/2017	Streamflow duration	441,000
Google	11/27/2017	Streamflow duration field assessment	286,000
Google	12/6/2017	Univoltine aquatic	51,200
Google Scholar	12/8/2017	"Hydrologic regime" AND "Arid Southwest"	200
Google Scholar	11/27/2017	Arid Southwest	604,000
Google Scholar	11/27/2017	Biological indicators	3,160,000
Google Scholar	11/27/2017	Clean Water Act jurisdiction	120,000
Google Scholar	11/27/2017	Ephemeral streams	112,000
Google Scholar	11/27/2017	Intermittent streams	201,000
Google Scholar	11/27/2017	Merovoltine aquatic	105
Google Scholar	11/27/2017	Perennial streams	161,000
Google Scholar	11/27/2017	Semivoltine aquatic	1,280
Google Scholar	11/27/2017	Streamflow duration	79,200
Google Scholar	11/27/2017	Univoltine aquatic	5,500
Web of Science	12/11/2017	"Arid Southwest" 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")	96
Web of Science	12/11/2017	Arid Southwest	1,405
Web of Science	12/11/2017	Biological indicator*	60,024
Web of Science	12/11/2017	Clean Water Act jurisdiction	48
Web of Science	12/11/2017	Ephemeral stream*	1,502

Web of Science	12/11/2017	Hydrologic regime*	3,060
Web of Science	12/11/2017	Intermittent stream*	2,521
Web of Science	12/11/2017	Merovoltine aquatic	1
Web of Science	12/11/2017	Perennial stream*	1,582
Web of Science	12/11/2017	Semivoltine aquatic	32
Web of Science	12/11/2017	Streamflow duration	1,716
Web of Science	12/11/2017	Univoltine aquatic	195

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.

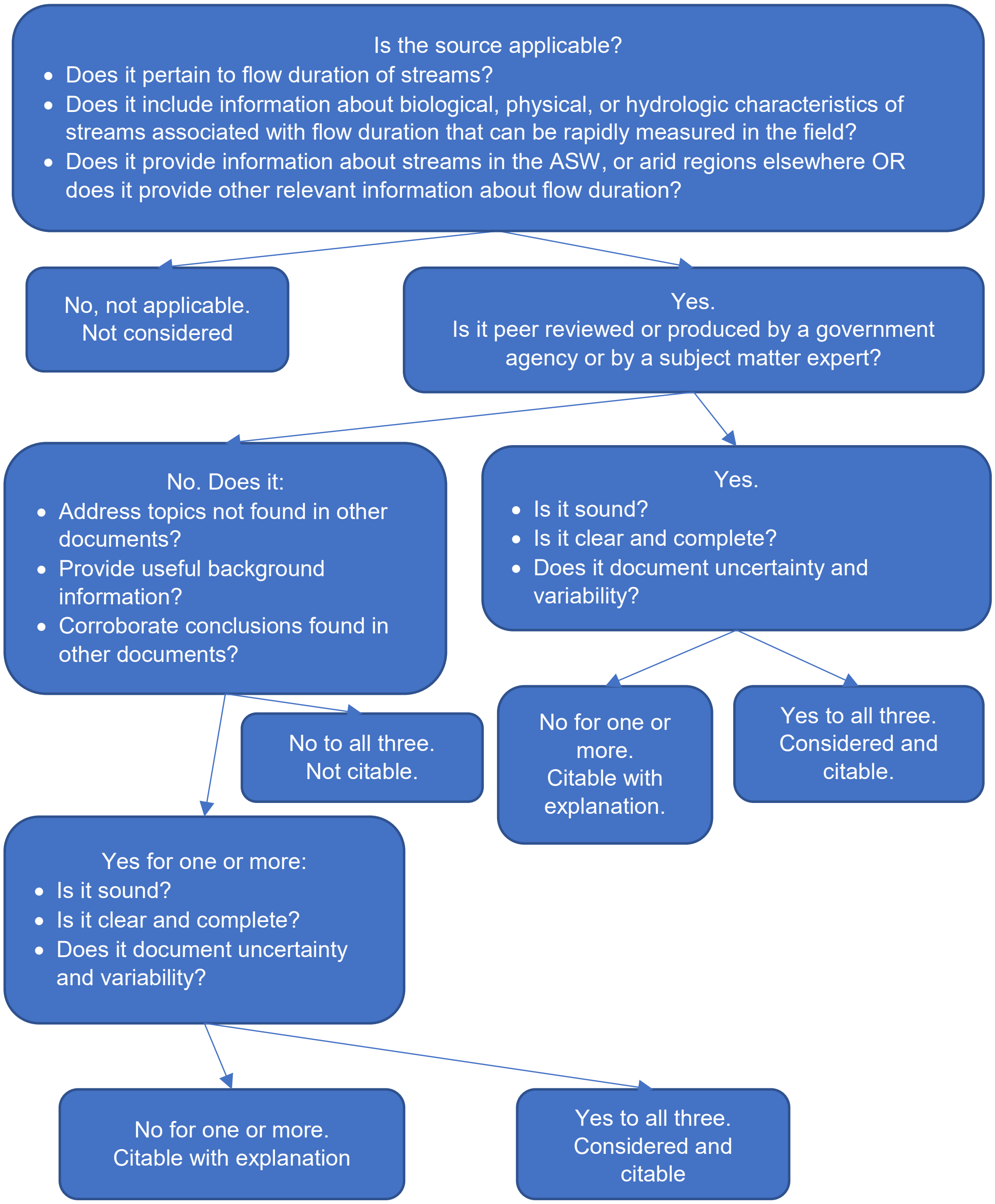

Figure 3. Decision tree for reviewing sources.

Applicability/Utility: Sources that provide information about the biological, physical, or hydrologic characteristics of streams along a flow duration gradient in the ASW were considered applicable. Sources in regions outside the ASW 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:

ftp://ftp.sccwrp.org/pub/download/PROJECTS/ASW_flow_duration_literature.enlx

Flow duration assessment methods

Six methods were appropriate for evaluating flow-duration classes in the ASW (Table 2). Only one of these methods is specifically designed for use in the ASW, but the rest were considered applicable because they included rapid field methods for determining stream classes. 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 ASW; 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.

Source	Geographic location	Represented classes	Indicators		
			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, episodic-ephemeral, perennial; Hyperrheic, eurheic, oligorheic, arheic, hyporheic/dry			Hydrologic metrics (based 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

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
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
Aquatic macroinvertebrates - Indicator taxa		X	X		X	X	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
Water column organic C		X		X	X	No		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

Pacific Northwest

For purposes of classifying perennial, intermittent and ephemeral streams in the Pacific Northwest (including the arid interior of that region), 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 ASW. 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.

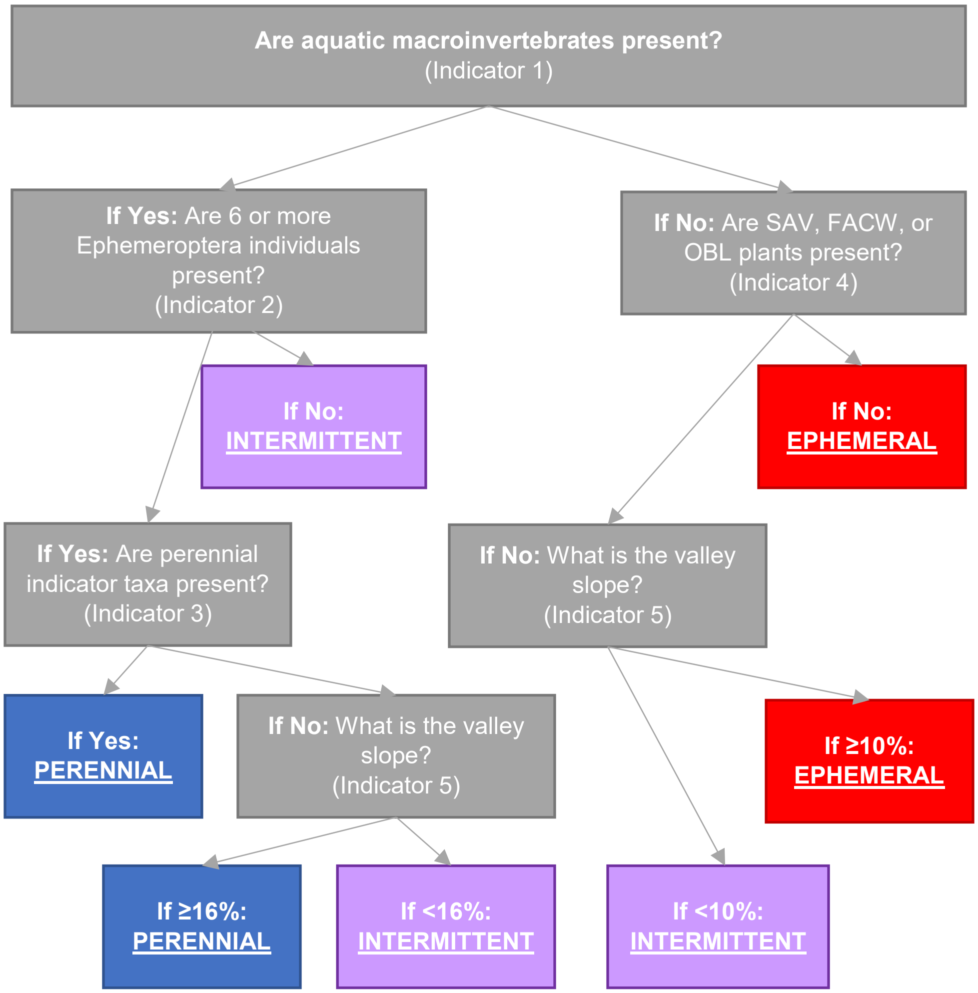

Figure 4. Flowchart used to determine flow class in the Pacific Northwest method (adapted from Nadeau 2015).

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. 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). The first phase is more rapid and may be 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 ***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. This method is intended for application in an arid region outside the ASW. The first step in analysis is determining the flow duration of a stream using the Temporary Stream Regime Tool (TRS-Tool; Gallart et al. 2012, Gallart et al. 2017). The TRS-Tool uses three potential sources of flow estimation/observation to determine stream flow classification: 1) Interviews, 2) interpretation of high-resolution aerial photographs and rapid field observation, and 3) outputs from hydrologic rainfall-runoff models.

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

Methodology for interviews is documented in Gallart et al. (2016). Interviews target locals encountered in the vicinity of a stream in question, 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 hydrologic models have been developed for portions of the ASW, such as Southern California (Sengupta et al. 2018), but not for most of the region, and are therefore not applicable to this study.

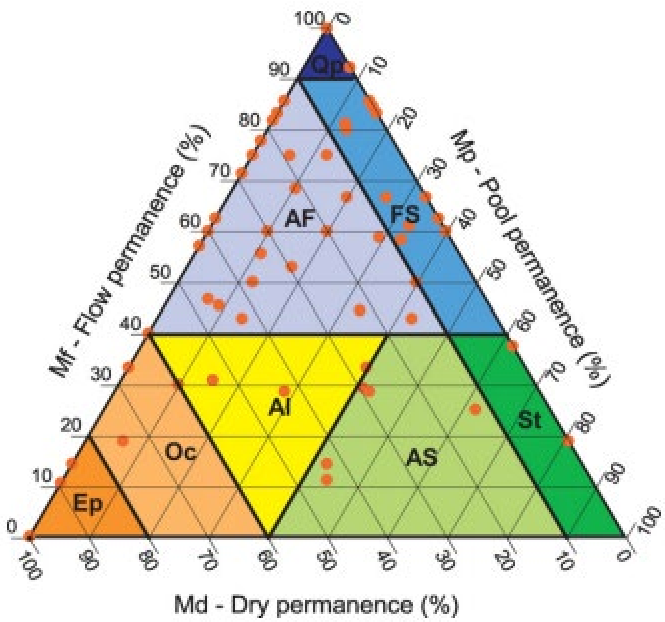

Figure 5. Plot used for classifying flow duration based on three metrics calculated from hydrologic model outputs.

North Carolina

This method, developed by the North Carolina Division of Water Quality (2010), looks at several biological, geomorphic, and hydrologic features to determine if a stream is perennial, intermittent, or ephemeral, as well as to designate locations in the landscape as origins of streamflow. 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. This method was developed for a region that receives considerably more rainfall than the ASW.

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. 2008; 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, outside the ASW.

INDICATORS IN THE ARID SOUTHWEST

A review of literature describing indicators in the ASW 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 6. We discuss each class of indicators and determine whether specific indicators should be included in the evaluation of flow duration assessment methods in the ASW, 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 ASW are defined primarily by Lichvar et al. (2008). 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). In a study of ephemeral channel morphology in the Sonoran Desert, Sutfin et al. (2014) and Seong et al. (2016) show that several indicators of perennial/intermittent flows in Topping et al. (2009) and NMED (2011) (e.g., erosional and depositional features, like sandbars) may be readily observed. Therefore, the defensibility of these indicators is open to question, at least outside of low-power headwater streams.

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). Climatic conditions in the ASW may complicate the interpretation of these indicators. For example, the absence of leaf litter in ephemeral streams in the ASW may be due to the lack of inputs rather than hydrologic removal (Strojan et al. 1987, Schade and Fisher 1997). The slow decomposition of organic matter in dry climates may result in wrack lines deposited during ephemeral flows that persist for a long time, meaning that they too could be an erroneous indicator of intermittent flow (Strojan et al. 1987, Anderson et al. 2003). 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 few studies showed that water chemistry is distinct in intermittent and perennial streams (e.g., Bonada et al. 2006, Mazor et al. 2014, 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.

Biological Indicators

In contrast to the many of the other indicators mentioned above, biological indicators are truly related to flow duration, rather than to stream power. Consequently, many studies corroborated relationships between these indicators and flow duration, particularly aquatic macroinvertebrates and plants. A number of studies suggest that additional biological indicators (e.g., terrestrial arthropods, diatoms, birds) may also be valuable in assessing flow duration.

Aquatic macroinvertebrates

Several methods presume that ephemeral streams are unable to support aquatic macroinvertebrates, with the exception of short-lived taxa like Culicidae. However, De Jong et al. (2015) sampled ephemeral streams in 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.

Many studies provide 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., Lawrence et al. 2010, Mazor et al. 2014, Schriever et al. 2015), 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 ASW. However, a few studies show that some taxa exhibit different habitat affinities in the ASW. 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.

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). Freshwater mussels are extirpated from many streams in the ASW where they historically occurred, and may be restricted to a single species (*Anodonta nutalliana*) in a few drainages in eastern Arizona and Inyo County, California (Blevins et al. 2017). While they are likely to be good indicators of perennial flow, some species have been observed in perennial pools within intermittent streams (e.g., Clark 2010). In general, they are unlikely to be relevant in this region due to their limited distribution. 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 King et al. (2015).

Mayflies

No mayfly families are considered to be an indicator of perennial flow in Blackburn (2012), although several studies suggest that some taxa show a preference for perennial flow (e.g., Isonychidae, King et al. 2014). Some studies support Baetidae as a perennial indicator (e.g., Bonada et al. 2006), while others suggest they prefer intermittent flow (e.g., Miller and Brasher 2011, King et al. 2015).

Stoneflies

Several studies supported the use of perlid stoneflies as indicators of perennial flow (e.g., Bonada et al. 2006, King et al. 2015, 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 ASW.

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).

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, Bogan and Lytle 2007, Miller and Brasher 2011, Bogan et al. 2013, King et al. 2015). However, del Rosario and Resh (2000) report three of these families (all but Philopotamidae) at low abundances in an intermittent stream with hyporheic refugia in close proximity to a perennial stream. Several studies suggested that additional families, such as Brachycentridae or Calamoceratidae, may also be a good indicator of perennial flow in parts of the ASW (Bonada et al. 2006, Bogan and Lytle 2011, Miller and Brasher 2011).

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. 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).

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).

Megaloptera

Although Corydalidae are listed as an indicator of perennial streams in Blackburn (2012), Bogan and Lytle (2007) considered them to be indicative of intermittent conditions. Cover et al. (2014) 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 6), 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 6. 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, Brasher and Miller 2011). However, challenges with identifying this group in the field may make them impractical for use in a field-based flow duration assessment method.

Other aquatic macroinvertebrates

Abedus, a large, conspicuous giant water bug (Belostomatidae) that is easily identified in the field, has been proposed as an indicator of perennial flow (Bogan and Lytle 2011).

Terrestrial arthropods

Two studies in the ASW show that riparian arthropod communities can differentiate streams by flow duration (McCluney and Sabo 2012, Moody and Sabo 2017). Table 3 in Moody and Sabo (2017) identifies several taxa found in riparian areas that can discriminate between ephemeral, intermittent, and perennial stream classes. Woodlice (Armadillidae), harvestmen (Phalangidae), wolf spiders (Lycosidae) and rove beetles (Staphylinidae) were indicative of perennial streams, while crickets (Gryllidae, Raphidophoridae) of intermittent streams. Several species of ants (Formicidae) indicated intermittency as well, while other ant taxa indicated ephemeral streams. Similarly, several ground beetles (Carabidae) indicated perenniality, while others indicated intermittency.

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

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

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 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.

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. Several studies show a very strong relationship between flow duration and plant communities (e.g., Auble et al. 2005, Stromberg et al. 2007). Stromberg et al. (2007) showed wetland plants (groundwater-dependent phreatophytes in particular) declined or disappeared where perennial flows were eliminated on portions of the San Pedro River. Thus, the taxonomic composition of riparian and wetland plants may be an effective indicator of flow duration.

Distinctness of riparian corridors is used as indicators of intermittent or perennial flow in Topping et al. (2009) and as a secondary indicator in Nadeau (2015). However, ephemeral streams may support “xeroriparian corridors” that are taxonomically and visually distinct from surrounding uplands (de Soyza et al. 2004, Stromberg et al. 2015, Stromberg et al. 2017). Additionally, in highly developed areas, surrounding uplands may be completely replaced with managed vegetation, preventing comparison with the riparian community. Thus, the simple presence of a riparian corridor (without consideration of species composition) may not be an effective indicator of flow duration in the ASW.

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 ASW through consultation with regional experts. For example, few of the salamander species listed in Nadeau (2015) are found in the ASW, while other aquatic taxa (e.g., *Taricha torosa, Thamnophis hammondii*) are endemic to this area. Therefore, habitat preferences of taxa specific to the ASW will need to be developed if they are to be used as an indicator of flow duration classes.

Although aquatic vertebrates do not depend on ephemeral streams to complete their life-cycles, De Jong et al. (2015) report that fish and amphibians may use them as migration corridors between perennial segments. Thus, they may be observed incidentally in flowing ephemeral streams.

Birds are generally poor indicators of local conditions at a stream-reach due to their high motility and migratory nature. Although some species have relatively high site fidelity and show preferences for particular flow duration classes, this pattern is mediated by vegetation (Brand et al. 2010, Merrit and Bateman 2012), which can be more directly and easily measured as a field indicator.

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)
- Sinuousity (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)

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)
- 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 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 6. Select examples of ASW indicators and levels associated with flow-duration classes.

Source	Region	Notes	Indicator Class	Perennial	Intermittent	Ephemeral
Bogan et al. (2017)	Northern California - John West Fork	Late-season pools only	BMI Richness	Higher, especially late summer (Sep-Oct). Ie. 45 taxa vs. 30	Lower, especially in summer. Ie. 30 vs 45.	
			BMI Taxa	**Exclusive:** *Rhithrogena, Parthina, Parakiefferiella, Ordobrevia nubifera, Flumincola* and *Dugesia*. **Associated:** *Paraleptophlebia, Centroptilum, Microvela, Ecclisomyia, Heteroplectron, Parametriocnemous, Leucrotuca, Physidae, Dixella, Polycentropus, Lepidostoma, Apsectrotanypus, Polypedilum laetum, Bezzia/Palpamyia, Lepidostoma unicolor*	*Psychoglypha, Neophylax* and *Leucrocuta*.	

			BMI Density	Lower, especially in summer. Eg hundreds per m^2 vs thousands.	Higher, especially in summer. Eg. >1000 per sqm vs hundreds	
Auble et al. (2005)	Utah - Fremont River, Capitol Reef National Park	>= 50% max probability of occurance within wetland innundation indicators	Vegetation Taxa			**Low Association:** FACW and OBL species *(Agrostis stolonifera, Alnus incana ssp. tenuifolia, Eleocharis palustris, Equisetum hyemale, Juncus balticus, Mentha arvensis, Poa compressa, Ranunculus cymbalaria, Salix exigua, Solidago canadensis)*
Bogan et al. (2013)	Arizona - San Pedro River and headwaters near the Huachuca Mtns (Babocomari River, Garden Canyon, Banning Creek)		BMI Richness	**Headwaters:** 32.2 ± 2.0 **Rivers:** 22.8 ± 2.1	10.5 ± 0.4	
			BMI Abundance	**Headwaters:** 453 ± 75 **Rivers:** 1745 ± 350	545 ± 81	
			Chironomidae % abundance	**Headwaters:** 32.5 ± 3.4 **Rivers:** 32.5 ± 3.4	79.6 ± 3.6	
		p-value = 0.20	Collector-filterer % abundance	**Headwaters:** 9.6 ± 1.6 **Rivers:** 7.0 ± 2.1	6.5 ± 2.0	
			Collector-gatherer % abundance	**Headwaters:** 61.2 ± 4.1 **Rivers:** 80.2 ± 5.9	76.4 ± 3.3	
			Piercer % abundance	**Headwaters:** 0.6 ± 0.4 **Rivers:** 0.3 ± 0.1	0	
			Predator % abundance	**Headwaters:** 15.3 ± 2.4 **Rivers:** 7.9 ± 4.2	1.1 ± 0.3	
		p-value = 0.19	Scraper % abundance	**Headwaters:** 8.1 ± 2.0 **Rivers:** 4.5 ± 2.5	8.2 ± 1.1	
			Shredder % abundance	**Headwaters:** 5.2 ± 1.7 **Rivers:** 0.2 ± 0.2	7.8 ± 3.1	

		Indicator taxa analysis; IV provided in the paper	BMI Taxa	**Headwaters:** *Caloparyphus, Phylloicus, Stempellinella, Tvetenia bavarica group, Caenis, Nixe, Polycentropus, Nilotanypus, Neoplasta, Heterelmis, Tinodes, Pyrgulopsis, Baetis*. **Rivers:** *Tricorythodes, Acentrella, Thienemanniella, Hydropsyche,* Cambaridae, *Ceratopogon, Oxyethira,* Ostracoda, *Cricotopus⁄Orthocladius, Atractides, Tanytarsus,* Oligochaeta, *Homoleptohyphes*	*Eukiefferiella rectangularis group, Hydrobaenus, Diamesa, Chaetocladius piger group, Mesocapnia arizonensis, Krenosmitta*	
De Jong et al. (2015)	Arizona/New Mexico - Santa Cruz River; Rio Puerco		BMI Reproductive Taxa			82.6% aerially dispersing adults
			BMI FFG Taxa			Mostly gatherer-collectors (28) and predators (41); 3-6 taxa for other groups
			Fish Taxa			*Lepomis cyanellus, Agosia chrysogasler, Pimephales promelas, Gambrusia affinis*
			Amphibian taxa			*Rana catesbeiana, Scaphiopus couchi, Spea bombifrons, Anaxyrus punctatus, Bufo sp.*
Katz et al. (2012)	SW Arizona - Lower Cienega Creek; Hassayampa River; Lower San Pedro RIver	Includes ephemeral streams; not all taxa reported	Vegetation Taxa	**Exclusive:** *Typha domingensis, Equisetum laevigatum, Eleocharis spp.*	**Exclusive/predominate:** *Monolepis nuttalliana, Polanisia dodecandra ssp. trachysperma, Polygonum aviculare*	
	San Pedro River		Vegetation Unique Taxa #	29	33	18

	Hassayampa River		Vegetation Unique Taxa #	12	16	12
	Cienega Creek		Vegetation Unique Taxa #	15	21	13

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*".

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

Surface Water Quality Bureau, New Mexico Environment Department. (2011). *HYDROLOGY PROTOCOL FOR THE DETERMINATION OF USES SUPPORTED BY EPHEMERAL, INTERMITTENT, AND PERENNIAL WATERS*. Retrieved from https://www.env.nm.gov/swqb/documents/swqbdocs/MAS/Hydrology/HydrologyProtocolAPPROVED05-2011.pdf

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Surface Water Quality Bureau, New Mexico Environment Department. (2012). *Hydrology Protocol Use Attainability Analysis for an Ephemeral Stream (Cover Sheet, Dec 2012)*. Retrieved from https://www.env.nm.gov/swqb/documents/swqbdocs/MAS/Hydrology/HydrologyCoverSheetREVDec2012.docx

Surface Water Quality Bureau, New Mexico Environment Department. (2011). *Hydrology Determination Field Sheets (May 2011)*. Retrieved from https://www.env.nm.gov/swqb/documents/swqbdocs/MAS/Hydrology/HydrologyFieldSheetsREVMay2011.docx

North Carolina

N C Division of Water Quality. (2010). *Methodology for Identification of Intermittent and Perennial Streams and their Origins* (Version 4.11). North Carolina Department of Environment and Natural Resources. Retrieved from http://portal.ncdenr.org/web/wq/swp/ws/401/waterresources/streamdeterminations

Related Sources

Fritz, K. M., Wenerick, W. R., & Kostich, M. S. (2013). A validation study of a rapid field-based rating system for discriminating among flow permanence classes of headwater streams in South Carolina. *Environmental Management*, *52*(5), 1286–1298. https://doi.org/10.1007/s00267-013-0158-x

Pacific Northwest (Including Oregon)

Nadeau, T.-L. (2015). *Streamflow Duration Assessment Method for the Pacific Northwest* (No. EPA 910-K-14-001). U.S. Environmental Protection Agency, Region 10, Seattle, WA.

Related Sources

Nadeau, T.-L. (2011). *2011 Streamflow Duration Assessment Method for Oregon* (No. EPA 910-R-11-002). U.S. Environmental Protection Agency, Region 10.

Nadeau, T.-L., Leibowitz, S. G., Wigington, P. J., Jr, Ebersole, J. L., Fritz, K. M., Coulombe, R. A., … Blocksom, K. A. (2015). Validation of rapid assessment methods to determine streamflow duration classes in the Pacific Northwest, USA. *Environmental Management*, *56*(1), 34–53. https://doi.org/10.1007/s00267-015-0466-4

Topping, B. J. D., Nadeau, T.-L., & Turaski, M. R. (2009). *Oregon Streamflow Duration Assessment Method Interim Version - Interim version (March 2009)*.

Temperate US

Fritz, K. M., Johnson, B. R., & Walters, D. M. (2006). *Field Operations Manual for Assessing the Hydrologic Permanence and Ecological Condition of Headwater Streams* (No. EPA/600/ R-06/126). U.S. Environmental Protection Agency, Office of Research and Development, Washington DC.

Excluded Methods

Berhanu, B., Seleshi, Y., Demisse, S. S., & Melesse, A. M. (2015). Flow Regime Classification and Hydrological Characterization: A Case Study of Ethiopian Rivers. *WATER*, *7*(6), 3149–3165. https://doi.org/10.3390/w7063149

Rational for Exclusion: Low utility. Analysis of flow duration class requires flow metrics extracted from observed or modeled daily flow data, and is therefore not a rapid method.

Berkowitz, J., Casper, A. F., & Noble, C. (2011). A multiple watershed field test of hydrogeomorphic functional assessment of headwater streams—Variability in field measurements between independent teams. *Ecological Indicators*, *11*(5), 1472–1475. https://doi.org/10.1016/j.ecolind.2011.01.004

Rational for Exclusion: Low applicability and utility. This study may be useful in estimating expected errors in field measured hydrogeomorphic flow duration indicators, but there is no direct application for these indicators in direct assessment of flow duration.

Kennard, M. J., Pusey, B. J., Olden, J. D., Mackay, S. J., Stein, J. L., & Marsh, N. (2010). Classification of natural flow regimes in Australia to support environmental flow management. *Freshwater Biology*, *55*(1), 171–193. https://doi.org/10.1111/j.1365-2427.2009.02307.x

Rational for Exclusion: Low utility. Methods of determining hydrologic regime here rely upon mean daily discharge data.

Noble, C. V., Berkowitz, J., & Spence, J. (2010). *Operational Draft Regional Guidebook for the Functional Assessment of High-gradient Ephemeral and Intermittent Headwater Streams in Western West Virginia and Eastern Kentucky*. US Army Corps of Engineers, Vicksburg. Retrieved from http://www.lrh.usace.army.mil/Portals/38/docs/Operational%20Draft%20Regional%20Guidebook1.pdf

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